CHAPTER 8

COLLECTION OF SOLID WASTE

Collection of unseparated (commingled) and separated solid waste in an urban area is difficult and complex because the generation of residential and commercial-industrial solid waste takes place in every home, every apartment building, and every commercial and industrial facility as well as in the streets, parks, and even vacant areas. The mushroom-like development of suburbs all over the country has further complicated the collection task.

As the patterns of waste generation become more diffuse and the total quantity of waste increases, the logistics of collection become more complex. Although these problems have always existed to some degree, they have now become more critical because of the high costs of fuel and labor. Of the total amount of money spent for collection, transportation, and disposal of solid wastes in 1992, approximately 50 to 70 percent was spent on the collection phase. This fact is important because a small percentage improvement in the collection operation can effect a significant savings in the overall cost.

The collection operation is considered from four aspects in this chapter: (1) the types of collection services that are provided, (2) the types of collection systems and some of the equipment now used as well as the associated labor requirements, (3) an analysis of collection systems, including the component relationships that can be used to quantify collection operations, and (4) the general methodology involved in setting up collection routes.

8-1 WASTE COLLECTION

The term *collection*, as noted in Chapter 1, includes not only the gathering or picking up of solid wastes from the various sources, but also the hauling of these wastes to the location where the contents of the collection vehicles are emptied. The unloading of the collection vehicle is also considered part of the collection operation. While the activities associated with hauling and unloading are similar for most collection systems, the gathering or picking up of solid waste will vary with the characteristics of the facilities, activities, or locations where wastes are generated (see Table 3-1) and the methods used for onsite storage of accumulated wastes between collections. The principal types of collection services now used for unseparated (commingled) and separated wastes are described below.

Collection of Unseparated (Commingled) Waste

The collection of wastes from low-rise detached dwellings, from medium-rise apartments, from high-rise apartments, and from commercial/industrial facilities is considered in the following discussion. The collection of wastes separated at the source is considered following this discussion.

From Low-Rise Detached Dwellings. The most common types of residential collection services for low-rise detached dwellings include (1) curb, (2) alley, (3) setout-setback, and (4) setout. Where curb service is used, the homeowner is responsible for placing the containers to be emptied at the curb on collection day and for returning the empty containers to their storage location until the next collection. Where alleys are part of the basic layout of a city or a given residential area, alley storage of containers used for solid waste is common. In setout-setback service, containers are set out from the homeowner's property and set back after being emptied by additional crews that work in conjunction with the collection crew responsible for loading the collection vehicle. Setout service is essentially the same as setout-setback service, except that the homeowner is responsible for returning the containers to their storage location. These services are compared in Table 8-1.

Manual methods used for the collection of residential wastes include (1) the direct lifting and carrying of loaded containers to the collection vehicle for emptying, (2) the rolling of loaded containers on their rims to the collection vehicle for emptying, and (3) the use of small lifts for rolling loaded containers to the collection vehicle. Large containers (referred to as *tote containers*) or drop cloths (often called *tarps*), into which wastes from small containers were emptied before being carried and/or rolled to the collection vehicle, are still used in some communities. For curb collection where collection vehicles with low loading heights are used, the collection crew transfers the wastes directly from the containers in which they are stored or carried to the collection vehicle (see Fig. 8-1). In other cases, collection vehicles are equipped with auxiliary containers into which the wastes are emptied. The auxiliary containers are then emptied into the collection vehicle by mechanical means. Still another variant involves the use of small satellite vehicles. Wastes are emptied into a large container carried by a satellite vehicle. When the container is loaded, the satellite vehicle is driven to

TABLE 8-1
Comparison of residential MSW collection services

Considerations	Type of service: Curb	Curb (mechanized)	Alley	Setout-setback	Setout	Backyard carry
Requires homeowner cooperation:						
To carry full containers	Yes	Yes	Optional	No	No	No
To carry empty containers	Yes	Yes	Optional	No	Yes	No
Requires scheduled service for homeowner cooperation	Yes	Yes	No	No	Yes	No
Poor aesthetically:						
Spillage and litter problem	High	Moderate	High	Low	High	Low
Containers visible	Yes	Yes	No	No	Yes	No
Attractive to scavengers	Yes	Yes	Highest	No	No	No
Prone to upsets	Yes	No	Yes	No	Yes	No
Number of persons in crew						
Typical	2	2	1	3	3	3
Range	1 to 3	1 to 2	1 to 3	3 to 7	1 to 5	3 to 5
Crew time	Low	Low	Low	Great	Medium	Medium
Collector injury rate due to lifting and carrying	Low	Low	Low	High	Medium	High
Trespassing complaints	Low	Low	Low	High	High	High
Special considerations		Requires standardized containers	Requires alleys and vehicles that can maneuver in them; less prone to block traffic; high vehicle and container depreciation rate			Requires wheeled caddy to roll filled barrels or the use of burlap carry cloth or hand-carry bin; works best with driveway
Cost due to size and time requirements	Low	Low	Low	High	Medium	Medium

(a) (b)

FIGURE 8-1
Collection of wastes placed at curb by homeowner: (a) Davis, California and (b) Venice, Italy.

the collection vehicle where the container is emptied into the truck by mechanical means (see Fig. 8-2).

Where mechanically loaded collection vehicles are used, the container used for the onsite storage of waste must be brought to the curb or other suitable collection site. Typically, 90-gal (340-L) containers are used in conjunction with mechanized collection vehicles (see Fig. 8-3).

From Low- and Medium-Rise Apartments. Curbside collection service is common for most low- and medium-rise apartments. Typically, the maintenance staff is responsible for transporting the containers to the street for curbside collection by manual or mechanical means. Where large containers are used, the containers are emptied mechanically using collection vehicles equipped with unloading mechanisms.

From High-Rise Apartments. Typically, large containers are used to collect wastes from large apartment buildings. Depending on the size and type of container used, the contents of the containers may be emptied mechanically using

(a) (b)

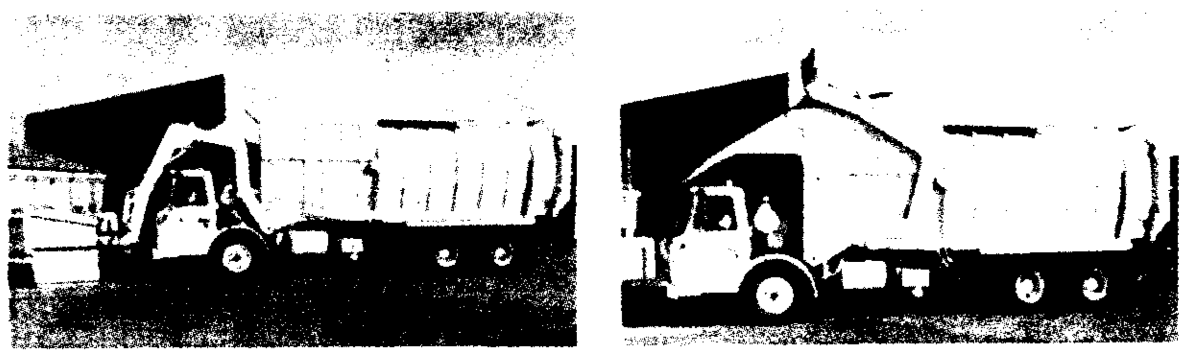
FIGURE 8-2
Satellite vehicle collection system: (a) loading of satellite vehicle equipped with 2-yd^3 container (note that in high-wind conditions, blowing of wastes is a problem) and (b) mechanical unloading of container contents of satellite vehicle.

(a) (b)

FIGURE 8-3
Typical example of mechanically loaded collection vehicle used for the collection of residential wastes: (a) collection of domestic wastes placed in large 90-gal (340-L) containers with mechanical articulated pickup mechanism and (b) closeup of pickup mechanism. Containers are brought to the curb by the homeowner.

collection vehicles equipped with unloading mechanisms (see Fig. 8-4), or the loaded containers may be hauled to an off-site location (e.g., a materials recovery facility) where the contents are unloaded (see Fig. 8-5).

From Commercial-Industrial Facilities. Both manual and mechanical means are used to collect wastes from commercial facilities. To avoid traffic congestion during the day, solid wastes from commercial establishments in many large cities are collected in the late evening and early morning hours. Where manual collection is used, wastes from commercial establishments are put into plastic bags, cardboard boxes and other disposable containers that are placed at the curb for collection. Waste collection is usually accomplished with a three- or, in some cases, four-person crew, consisting of a driver and two or three collectors who load the wastes from the curbside into the collection vehicle. In most off-hour collection operations, the driver remains with the collection vehicle for reasons of safety.



(a) (b)

FIGURE 8-4
Self-loading collection vehicle equipped with internal compactor: (a) approaching container to be emptied and (b) contents of container being emptied.

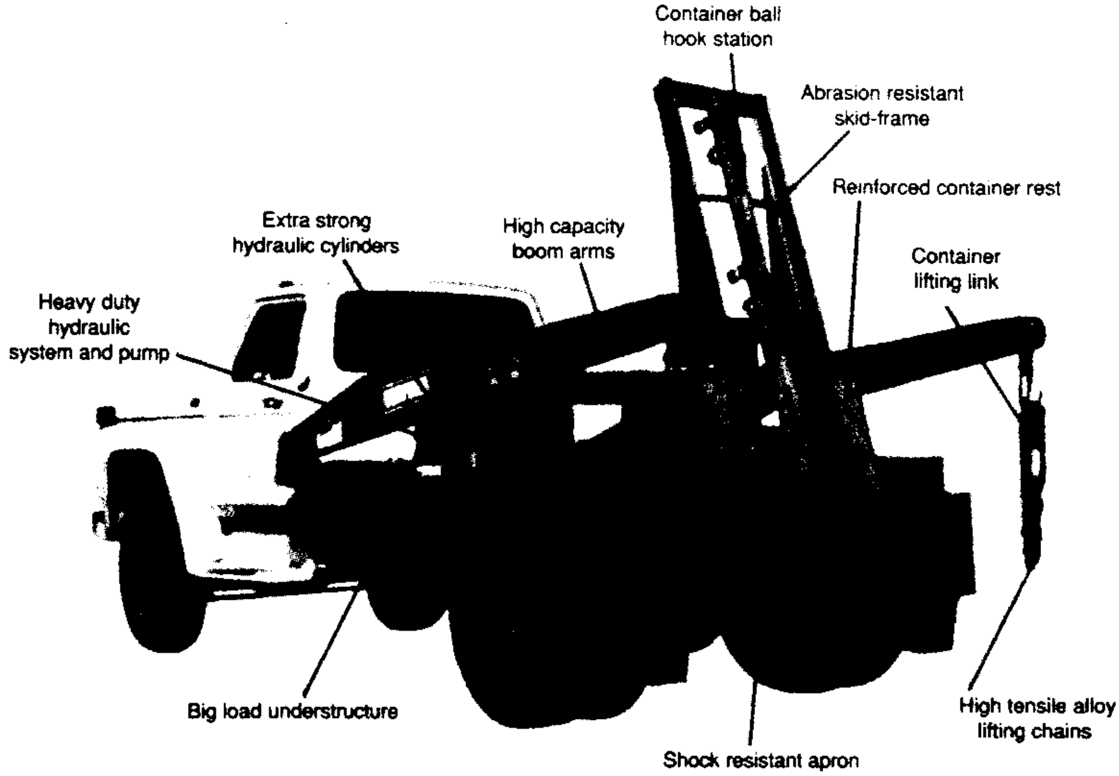


FIGURE 8-5
Collection vehicle used to haul and empty large containers (2 to 12 yd^3). Container hoist and unloading mechanism is mounted on truck frame. (Courtesy of Dempster Dumpster Systems.)

If congestion is not a major problem and space for storing containers is available, the collection service provided to commercial-industrial facilities centers on the use of movable containers (see Fig. 8-6), containers that can be coupled to large stationary compactors (see Fig. 8-7), and large-capacity open-top containers (see Fig. 8-8). Again, depending on the size and type of container used, the contents of the containers may be emptied mechanically

(a) (b)

FIGURE 8-6
Emptying sequence for containers used at commercial complex: (a) loaded containers are brought and attached to collection vehicle and (b) contents of container are emptied mechanically.

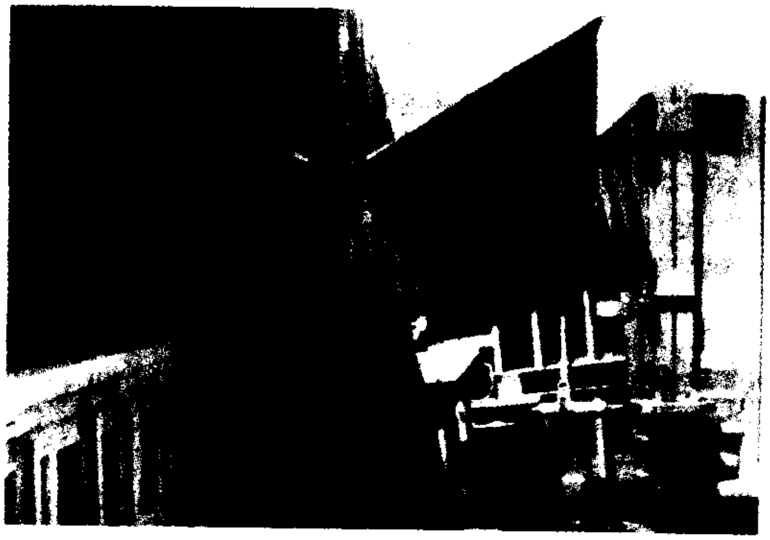


FIGURE 8-7
Stationary compactor used in conjunction with large container for the collection of wastes from commercial establishments.

or the loaded containers hauled to an off-site location where the contents are unloaded. To minimize the difficulties due to traffic congestion, mechanized collection can also be accomplished during the evening hours with a driver and helper.

Collection of Wastes Separated at the Source

Waste materials that have been separated at the source must be collected or gathered together before they can be recycled. The principal methods now used for the collection of these materials include curbside collection using conventional and specially designed collection vehicles, incidental curbside collection by charitable organizations, and delivery by homeowners to drop-off and buy-back centers. The curbside collection of wastes separated at the source is considered in the following discussion. The recovery of materials at drop-off and buy-back centers is considered in Chapter 9.

FIGURE 8-8
Large open-top containers used for the collection of wastes from commercial establishments.

Residential Curbside Collection. In a curbside system, source-separated recyclables are collected separately from commingled waste at the curbside, alley, or commercial facility. Because residents and businesses do not have to transport the recyclables any further than the curb, participation in curbside programs is typically much higher than for drop-off programs. Curbside programs vary greatly from community to community. Some programs require residents to separate several different materials (e.g., newspaper, plastic, glass, and metals), which are then stored in their own containers and collected separately. Other programs use only one container, to store commingled recyclables, or two containers, one for paper and the other for "heavy" recyclables, such as glass, aluminum and tin cans. Clearly, the method used to collect source-separated wastes will affect directly the layout and design of separation and processing facilities. The principal types of collection vehicles used for the collection of separated wastes are (1) standard collection vehicles and (2) specialized collection vehicles, including closed-body recycling trucks, recycling trailers, modified flatbed trucks, open-bin recycling trucks, and compartmentalized trailers. Four commonly used vehicles for the collection of source-separated waste are shown in Fig. 8-9. The characteristics of these specialized vehicles are reviewed in Table 8-2. Determination of the amount of each waste to be collected is illustrated in Example 8-1.

(a) (b) (c) (d)

FIGURE 8-9
Specially designed vehicles for the collection of source-separated waste: (*a*) open bin manually loaded, (*b*) open bin manually loaded mechanically emptied, (*c*) containers mechanically emptied, and (*d*) mobile container system.

TABLE 8-2

Characteristics of vehicles used for the collection of wastes separated at the source[a]

Item	Comment
Standard compactor trucks	Compactor trucks used for the collection of commingled waste can also be used for collection of recyclables. Many communities use compactor trucks in their recycling programs. Rear-loader compactors have been used for newspaper, cardboard and magazines, with trailers attached to them for cans and glass. Front-end loaders have been used to service large containers containing newspaper recovered from apartment buildings. Some cities used side- and rear-loading compactor trucks to pick up newspaper one week and glass and cans the next. When glass and cans are collected, the compacting mechanism is not used because glass is highly abrasive and would damage the packer plate. Also, by not compacting, the majority of the glass remains unbroken and is, therefore, easier to sort into different colors at the processing site.
Mobile container system	The mobile container system is essentially a steel frame with sets of hydraulic forks that can be used to transport large bins. The trailers range in size from three bins to six bins and have a low pull or gooseneck (fifth wheel) style. To load the trailer, the fork lifts are lowered to the ground and the bins are wheeled over them so that the forks slide into channels on the underside of the bins. The bins are then hydraulically raised and secured to the trailer frame. An empty set of bins can be left to replace the full ones. A pickup truck is used to pull the trailer.
Modified flatbed truck	Some curbside programs utlize a standard flatbed truck with a hydraulic dumping box mounted on the truck bed. The box is usually divided into three or four compartments and has a standard capacity of approximately 15 cubic yards.
Open-bin recycling truck	The open-bin recycling truck is a specially designed vehicle with two or three open-top, self-dumping bins. The front bins are typically 4 to 5 cubic yards and can be specified to unload right or left. The back bin, which dumps to the rear, has a capacity of 8 to 9 cubic yards. The cab can be designed for the right-hand stand-up drive to allow the loading function to be performed by the driver.
Closed-body recycling truck	This truck consists of an enclosed steel body installed on a lowered truck chassis, and a low entry walk-in cab with dual left- and right-hand driving controls (which allows for one-person operation). There are adjustable hinged dividers on the body that can be used to create from two to four compartments for different materials. One or both sides are open for manual loading. Removable aluminum side panels contain the load as the level of material rises. The overall capacity of the truck can range from 27 to 31 cubic yards, although operational capacity when manually loading is 20 to 25 cubic yards. The truck is equipped with a front-mounted telescopic hoist and rear body hinge for dumping. Each compartment is discharged separately by opening the rear door, unlocking the appropriate divider, and tipping the body.

[a] Adapted from Ref. 1.

Example 8-1 Home separation and curbside collection of recyclables. A community is purchasing specialized vehicles for the curbside collection of source-separated wastes. Three recycling containers are to be provided to each residence and residents will be asked to separate newspaper and cardboard, plastics and glass, and aluminum and tin cans. The homeowner is to place the separated materials in the appropriate containers and then move the recycling containers to curbside once per week for collection by special recycling vehicles. Estimate the relative volumetric capacity required for each material in recycling collection vehicles. Assume 80 percent of the recyclable material will be separated and that newsprint represents 20 percent of the total paper waste. The number of homes that will participate in the separation program is estimated to be 60 percent. If the separated wastes are to be collected from a subdivision of 1200 homes, determine the number of trips that will be required if the size of the collection vehicle is 15 yd^3. Assume 3.5 residents per residence.

Solution

1. Set up a computation table to calculate the relative volume of the recycled materials. Use the weight distribution data given in column 4, Table 3-7, and the specific weight values given in Table 4-1.

Component	Total solid wastes, lb	Waste materials separated, lb	Specific weight, lb/ft^3	Volume, ft^3
Organic				
Food wastes	8.0	—	18.0	—
Paper	35.8	5.7[a]	5.6	1.02
Cardboard	6.4	5.1	3.1	1.65
Plastics	6.9	5.5	4.1	1.34
Textiles	1.8	—	4.1	—
Rubber	0.4	—	8.1	—
Leather	0.4	—	10.0	—
Garden trimmings	17.3	—	6.3	—
Wood	1.8	—	14.8	—
Inorganic				
Glass	9.1	7.3	12.2	0.60
Tin cans	5.8	4.6	5.6	0.82
Aluminum	0.6	0.5	10.0	0.05
Other metal	3.0	—	20.0	—
Dirt, ashes, etc.	2.7	—	30.0	—
Total	100.0	28.7		5.48

[a] 5.7 lb = [(35.8 lb × 0.20) × 0.8]

2. Determine the relative volume of the recycled materials.
   (*a*) The volume in each category is:
      i. Newspaper + cardboard = 1.02 + 1.65 = 2.67 ft^3
      ii. Plastics + glass = 1.34 + 0.60 = 1.94 ft^3
      iii. Aluminum and tin cans = 0.82 + 0.05 = 0.87 ft^3

(b) The relative volumes of waste compared with aluminum plus tin cans are

i. Newspaper + cardboard = 3.1 (= 2.67 ft^3/0.87 ft^3)

ii. Plastics + glass = 2.2 (= 1.94 ft^3/0.87 ft^3)

iii. Aluminum and tin cans = 1.0

(c) Thus, if a 15 yd^3 collection vehicle is to be used, 7.3 yd^3 [(2.67/5.48) × 15] of the capacity would be allocated for newspaper and cardboard, 5.3 yd^3 for plastic and glass, and 2.4 yd^3 for aluminum and tin cans.

3. Determine the number of trips required to collect the separated materials.

(a) Estimate the total weekly solid waste production rate using the data from Table 6-3.

Solid waste production, lb/wk

$$= 3.5 \text{ persons } \times 7 \text{ d/wk } \times 3.82 \text{ lb/capita} \cdot \text{d } = 93.6 \text{ lb/wk}$$

(b) Estimate the total weekly quantity of separated newspaper and cardboard.

i. Separated newspaper, lb/wk

$$= 93.6 \text{ lb/wk} \times (5.7/100) = 5.3 \text{ lb/wk}$$

ii. Separated cardboard, lb/wk

$$= 93.6 \text{ lb/wk} \times (5.1/100) = 4.8 \text{ lb/wk}$$

(c) Estimate the total weekly volume of separated newspaper and cardboard.

i. Separated newspaper, ft^3/wk

$$= (5.3 \text{ lb/wk})/(5.6 \text{ lb/ft}^3) = 1.0 \text{ ft}^3\text{/wk}$$

ii. Separated cardboard, ft^3/wk

$$= (4.8 \text{ lb/wk})/(3.1 \text{ lb/ft}^3) = 1.5 \text{ ft}^3\text{/wk}$$

(d) Estimate the total number of weekly collection trips

Number of trips

$$= [(1.0 + 1.5) \text{ ft}^3\text{/wk} \cdot \text{ home}] \times 1200 \text{ homes}$$

$$\times 0.60 \text{ (percent participation rate)}/(27 \text{ ft}^3\text{/yd}^3)/(7.3 \text{ yd}^3\text{/trip})$$

$$= 9.1 \text{ trips/wk, say 9 trips/wk}$$

Comment. Although the numbers in this example will change, the approach is valid for any collection operation. In applying such an analysis, it will be important to prepare a sensitivity analysis to assess how variable the relative volumes may become as waste characteristics change and new regulations are implemented.

Commercial Facilities. Source-separated materials from commercial establishments are usually collected by private haulers. In many cases, the haulers have contracts with the establishments for the separated material. The wastes to be recycled are stored in separate containers. In some cities, cardboard is bundled and left at curbside where it is collected separately. In large commercial facilities baling equipment may be used for the paper and cardboard, and can crushers are used for the aluminum cans. Commingled MSW, generated in addition to the separated materials, is most commonly collected by private haulers or by city crews, if the city provides collection services.

8-2 TYPES OF COLLECTION SYSTEMS, EQUIPMENT, AND PERSONNEL REQUIREMENTS

Over the past 10 years a wide variety of systems and equipment have been used for the collection of solid wastes. These systems may be classified from several points of view, such as the mode of operation, the equipment used, and the types of wastes collected. In this text, collection systems have been classified according to their mode of operation into two categories: (1) hauled container systems (HCS) and (2) stationary container systems (SCS) [4]. In the former, the containers used for the storage of wastes are hauled to the disposal site, emptied, and returned to either their original location or some other location. In the latter, the containers used for the storage of wastes remain at the point of generation, except when they are moved to the curb or other location to be emptied. These two types of collection systems, and the corresponding personnel requirements for these systems are described in this section.

Hauled Container Systems

Hauled container systems are ideally suited for the removal of wastes from sources where the rate of generation is high, because relatively large containers are used (see Table 8-3). The use of large containers reduces handling time as well as the unsightly accumulations and unsanitary conditions associated with the use of numerous smaller containers. Another advantage of hauled container systems is their flexibility: containers of many different sizes and shapes are available for the collection of all types of wastes.

Because containers used in this system usually must be filled manually, the use of very large containers often leads to low-volume utilization unless loading aids, such as platforms and ramps, are provided. In this context, container utilization is defined as the fraction of the total container volume actually filled with wastes.

While hauled container systems have the advantage of requiring only one truck and driver to accomplish the collection cycle, each container picked up requires a round trip to the disposal site (or other transfer point). Therefore, container size and utilization are of great economic importance. Further, when highly compressible wastes are to be collected and hauled over considerable distances, the economic advantages of compaction are obvious.

There are three main types of hauled container systems: (1) hoist truck, (2) tilt-frame container, and (3) trash-trailer. Typical data on the collection vehicles used with these systems are reported in Table 8-4. Cost data for these vehicles are presented in Appendix E.

TABLE 8-3
Representative data on the capacities of containers available for use with various collection systems

Vehicle	Container type	Typical range of container capacities,[a] yd^3
Hauled container system		
Hoist truck	Used with stationary compactor	6–12
Tilt-frame	Open top, also called drop or debris boxes	12–50
	Used with stationary compactor	15–40
	Equipped with self-contained compaction mechanism	20–40
Truck-tractor	Open-top trash-trailers	15–40
	Enclosed trailer-mounted containers equipped with self-contained compaction mechanism	20–40
Stationary container systems		
Compactor, mechanically loaded	Enclosed top and side-loading	1–8
Compactor, mechanically loaded	Special containers used for the collection of residential wastes from individual residences	0.23–0.45 (60–120 gal)
Compactor, manually loaded	Small plastic or galvanized metal containers, disposable paper and plastic bags	0.08–0.21 (20–55 gal)

[a] See Table 7-2 for typical container dimensions.

Note: $yd^3 \times 0.7646 = m^3$

$gal \times 0.003785 = m^3$

Hoist Truck Systems. In the past, hoist trucks were widely used with containers varying in size from 2 to 12 yd^3 (see Fig. 8-5). With the advent of large capacity mechanically loaded collection vehicles, however, this system appears to be applicable in only a limited number of cases, the most important of which are as follows:

1. For the collection of wastes by a collector who has a small operation and collects from only a few pickup points at which considerable amounts of wastes are generated. Generally, for such operations the purchase of newer and more efficient collection equipment cannot be justified economically.
2. For the collection of bulky items and industrial rubbish such as scrap metal and construction debris that are not suitable for collection with compaction vehicles.

Tilt-Frame Container Systems. Systems that use tilt frame–loaded vehicles (see Fig. 8-10) and large containers, often called *drop* or *debris boxes*, are ideally suited for the collection of all types of solid waste and rubbish from locations where the generation rate warrants the use of large containers. As noted in Table 8-3, various types of large containers are available for use with tilt-frame collection vehicles. Open-top containers are used routinely at warehouses and construction

TABLE 8-4
Vehicles used for the collection of solid waste

Collection vehicle			Typical overall collection vehicle dimensions				
Type	Available container or truck body capacities,[a] yd^3	Number of axles	With indicated container or truck body capacity,[b] yd^3	Width, in	Height, in	Length,[c] in	Unloading method
Hauled container systems							
Hoist truck	6–12	2	10	94	80–100	110–150	Gravity, bottom opening
Tilt-frame	12–50	3	30	96	80–90	220–300	Gravity, inclined tipping
Truck-tractor trash-trailer	15–40	3	40	96	90–150	220–450	Gravity, inclined tipping
Stationary container system							
Compactor (mechanically loaded)							
Front loading	20–45	3	30	96	140–150	240–290	Hydraulic ejector panel
Side loading	10–36	3	30	96	132–150	220–260	Hydraulic ejector panel
Rear loading	10–30	2	20	96	125–135	210–230	Hydraulic ejector panel
Compactor (manually loaded)							
Side loading	10–37	3	37	96	132–150	240–300	Hydraulic ejector panel
Rear loading	10–30	2	20	96	125–135	210–230	Hydraulic ejector panel

[a] See Tables 8-2 and 7-2.

[b] See Table 7-2 for dimensions of typical containers.

[c] From front of the truck to the rear of container or truck body.

Note: $yd^3 \times 0.7646 = m^3$

$in \times 0.0254 = m$

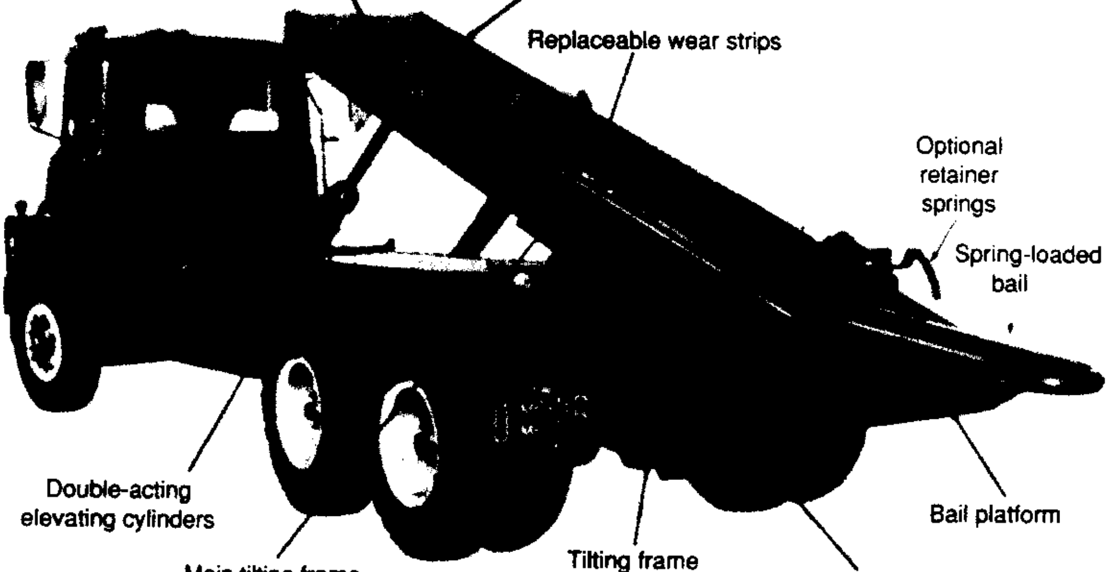


FIGURE 8-10
Truck with tilt-frame loading mechanism used to haul and unload large-capacity containers. (Courtesy of Dempster Dumpster Systems.)

sites (see Fig. 8-11). Large containers, in conjunction with stationary compactors, are common at apartment complexes, commercial services, and transfer stations. Because of the large volume that can be hauled, the use of the tilt-frame hauled container system has become widespread, especially among private collectors servicing commercial accounts.

Trash-Trailer Systems. The application of trash-trailers is similar to that for tilt-frame container systems. Trash-trailers are better for the collection of especially heavy rubbish, such as sand, timber, and metal scrap, and often are used for the collection of demolition wastes at construction sites (see Fig. 8-12).

FIGURE 8-11
Contents of large tilt frame–loaded container being emptied at landfill.

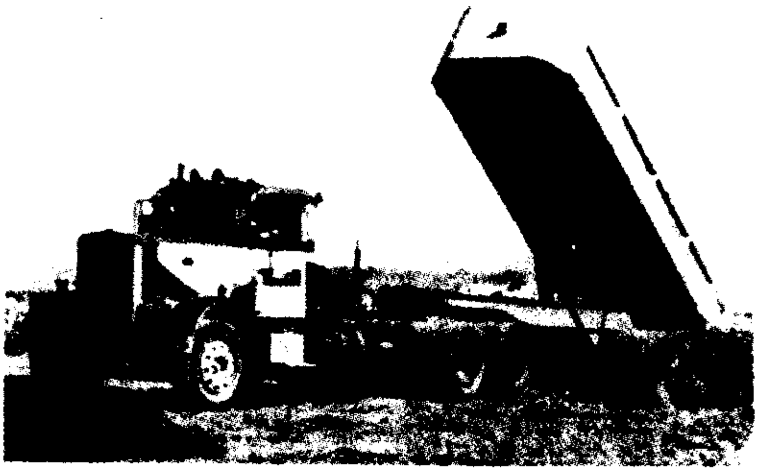


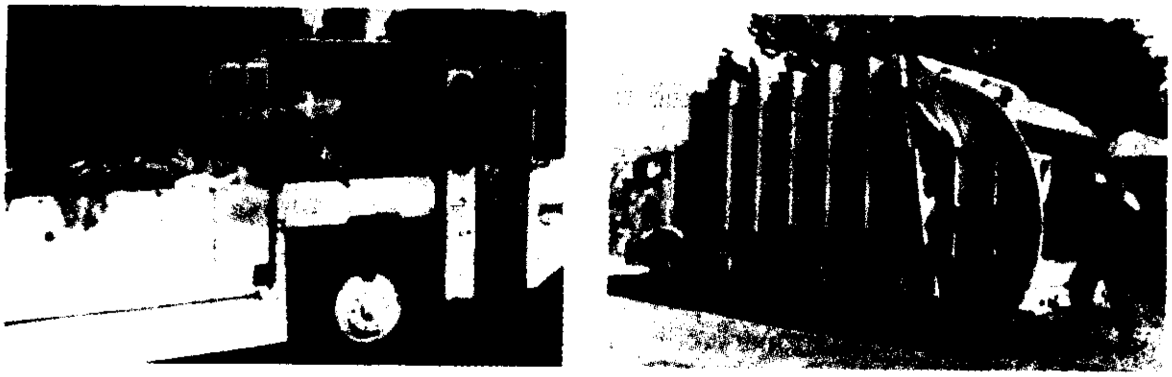
FIGURE 8-12
Contents of trash-trailer, used for demolition wastes, being unloaded at landfill.

Personnel Requirements for the Hauled Container System. In most hauled container systems a single collector-driver is used. The collector-driver is responsible for driving the vehicle, loading full containers onto the collection vehicle, emptying the contents of the containers at the disposal site (or transfer point), and redepositing (unloading) the empty containers. In some cases, for safety reasons, both a driver and helper are used. The helper usually is responsible for attaching and detaching any chains or cables used in loading and unloading containers on and off the collection vehicle; the driver is responsible for the operation of the vehicle. A driver and helper should always be used where hazardous wastes are to be handled.

Stationary Container Systems

Stationary container systems may be used for the collection of all types of wastes. The systems vary according to the type and quantity of wastes to be handled, as well as the number of generation points. There are two main types: (1) systems in which mechanically loaded collection vehicles are used (see Figs. 8-3, 8-4, and 8-6), and (2) systems in which manually loaded collection vehicles are used (see Figs. 8-1 and 8-13). Because of the economic advantages involved, almost all of the collection vehicles now used are equipped with internal compaction mechanisms. Data on the collection vehicles used in this system are reported in Table 8-4. Cost data for the collection vehicles used in the stationary container system are presented in Appendix E.

Systems with Mechanically Loaded Collection Vehicles. Container size and utilization are not so critical in stationary container systems using collection vehicles equipped with a compaction mechanism as they are in hoist-truck systems. Trips to the materials recovery facility (MRF), transfer station, or disposal site are made after the contents of a number of containers have been collected and compacted, and the collection vehicle is full. For this reason, the utilization of the driver in terms of the quantities of wastes hauled is considerably greater for these systems than for hauled container systems.



(a) (b)

FIGURE 8-13
Types of collection vehicles: (a) standup right-hand-drive side-loaded collection vehicle and (b) collector manually emptying the contents of a container into a rear-loaded compaction-type collection vehicle (this type of vehicle is commonly used with two- and three-person crews for the collection of residential and commercial wastes in many parts of the United States).

A variety of container sizes is available for use with these systems (see Table 8-3 and Figs. 8-3, 8-6, and 8-8). Containers vary from relatively small (60 gal) to sizes comparable with those handled with a hoist truck (see Table 8-3). Smaller containers offer greater flexibility in terms of shape, ease of loading, and special features available, and also lead to considerably increased utilization. These systems can also be used for the collection of residential wastes, substituting one large container for a number of small containers.

Because truck bodies are difficult to maintain and because of the weight involved, these systems are not well suited for the collection of heavy industrial wastes and bulk rubbish, such as that produced at construction and demolition sites. Locations where high volumes of rubbish are produced are also difficult to service because of the space requirements for the large number of containers.

Systems with Manually Loaded Collection Vehicles. The major application of manual loading methods is in the collection of residential wastes and litter (see Fig. 8-1*a*). Manual loading can compete effectively with mechanical loading in residential areas because the quantity picked up at each location is small and the loading time is short. In addition, manual methods are used for residential collection because many individual pickup points are inaccessible to mechanized self-loading collection vehicles.

Special attention must be given to the design of the collection vehicle intended for use with a single collector-driver. At present, it appears that a side-loaded compactor, such as the one shown in Figs. 8-1*a* and 8-13*a* equipped with standup right-hand drive, is best suited for curb and alley collection.

Transfer Operations. Transfer operations, in which the wastes, containers, or collection vehicle bodies holding the wastes are transferred from a collection vehicle to a transfer or haul vehicle, are used primarily for economic considerations. Transfer operations may prove economical when (1) relatively small, manually loaded collection vehicles are used for the collection of residential wastes and long haul distances are involved, (2) extremely large quantities of wastes must be hauled over long distances, and (3) one transfer station can be used by a number of collection vehicles. Transfer and transport operations are considered in detail in Chapter 10.

Personnel Requirements for Stationary Container Systems. The personnel requirements for the stationary collection system will vary depending on whether the collection vehicle is loaded mechanically or manually. Labor requirements for mechanically loaded stationary container systems are essentially the same as for hauled container systems. Where a helper is used, the driver often assists the helper in bringing loaded containers mounted on rollers to the collection vehicle and returning the empty containers. Occasionally, a driver and two helpers are used where the containers to be emptied must be rolled (transferred) to the collection vehicle from inaccessible locations, such as in congested downtown commercial areas.

In stationary container systems where the collection vehicle is loaded manually, the number of collectors varies from one to three in most cases, depending on the type of service and the collection equipment. Typically, two persons, a collector and a driver, are used for curb and alley service, and a multiperson crew is used for backyard carry service (see Table 8-1). In satellite-vehicle collection systems, one collector-driver is used for the main collection vehicle and one collector-driver is used with each satellite collection vehicle. While the satellite vehicles are being loaded, the collector-driver of the main vehicle picks up wastes from curb locations along the route. Although the aforementioned crew sizes represent current practices, there are many exceptions. In many cities multiperson crews are used for curb service as well as for backyard carry service.

8-3 ANALYSIS OF COLLECTION SYSTEMS

To establish vehicle and labor requirements for the various collection systems and methods, the unit time required to perform each task must be determined. By separating the collection activities into unit operations, it is possible (1) to develop design data and relationships that can be used universally and (2) to evaluate both the variables associated with collection activities and the variables related to, or controlled by, the particular location. The discussion that follows is intended to serve as an introduction to the types of information and data that are needed to evaluate waste collection operations and systems properly.

Definition of Terms

Before the relationships for collection systems can be modeled effectively, the component tasks must be delineated. The operational tasks for the hauled container and stationary container systems are shown schematically in Figs. 8-14 and 8-15, respectively. The activities involved in the collection of solid wastes can be resolved into four unit operations: (1) pickup, (2) haul, (3) at-site, and (4) off-route [5, 7].

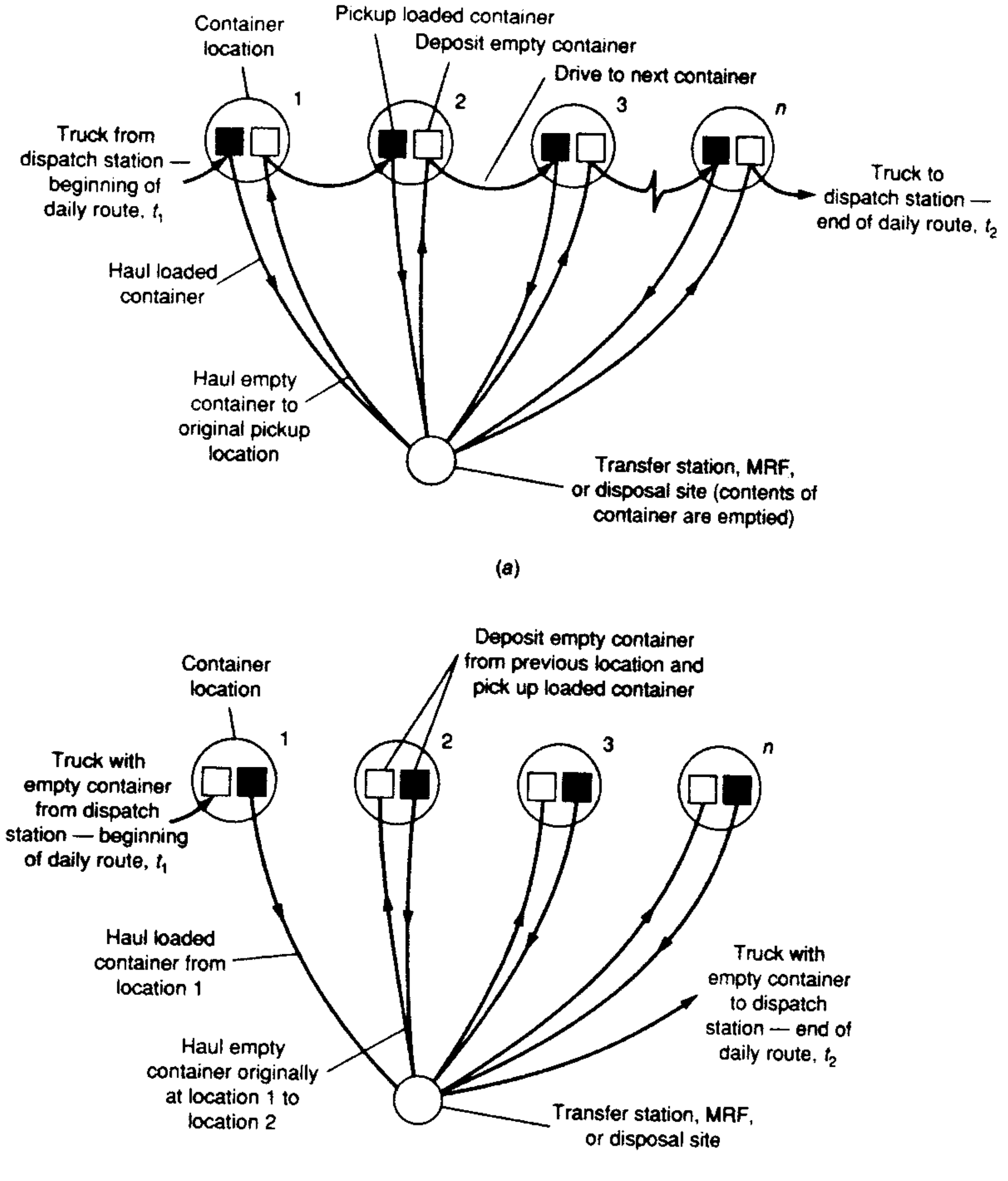


FIGURE 8-14
Schematic of operational sequence for hauled container system: (*a*) conventional mode and (*b*) exchange container mode.

Pickup. The definition of the term *pickup* depends on the type of collection system used.

1. For hauled container systems operated in the conventional mode (see Fig. 8-14*a*), pickup (P_{hcs}) refers to the time spent driving to the next container after an empty container has been deposited, the time spent picking up the loaded container, and the time required to redeposit the container after its contents

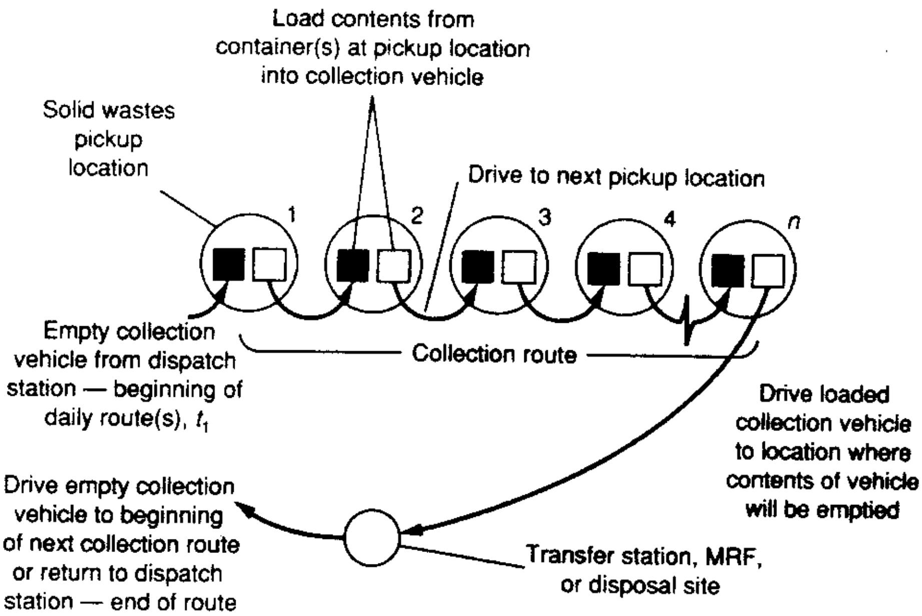


FIGURE 8-15
Schematic of operational sequence for stationary container system.

have been emptied. For hauled container systems operated in the exchange-container mode (see Fig. 8-14*b*), pickup includes the time required to pick up a loaded container and to redeposit the container at the next location after its contents have been emptied.

2. For stationary container systems (see Fig. 8-15), *pickup* (P_{scs}) refers to the time spent loading the collection vehicle, beginning with stopping the vehicle before loading the contents of the first container and ending when the contents of the last container to be emptied have been loaded. The specific tasks in the pickup operation depend on the type of collection vehicle as well as the collection methods used.

Haul. The definition of the term *haul* (h) also depends on the type of collection system used.

1. For hauled container systems, *haul* represents the time required to reach the location where the contents of the container will be emptied (e.g., transfer station, MRF, or disposal site), starting when a container whose contents are to be emptied has been loaded on the truck and continuing through the time after leaving the unloading location until the truck arrives at the location where the empty container is to be redeposited. Haul time does not include any time spent at the location where the contents of the container are unloaded.
2. For stationary container systems, haul refers to the time required to reach the location where the contents of the collection vehicle will be emptied (e.g., transfer station, MRF, or disposal site), starting when the last container on the route has been emptied or the collection vehicle is filled and continuing through the time after leaving the unloading location until the truck arrives at

the location of the first container to be emptied on the next collection route. Haul time does not include the time spent at the location where the contents of the collection vehicle are unloaded.

At-Site. The unit operation *at-site* (s) refers to the time spent at the location where the contents of the container (hauled container system) or collection vehicle (stationery container system) are unloaded (e.g., transfer station, MRF, or disposal site) and includes the time spent waiting to unload as well as the time spent unloading the wastes from the container or collection vehicle.

Off-Route. The unit operation *off-route* (W) includes all time spent on activities that are nonproductive from the point of view of the overall collection operation. Many of the activities associated with off-route times are sometimes necessary or inherent in the operation. Therefore, the time spent on off-route activities may be subdivided into two categories: necessary and unnecessary. In practice, however, both necessary and unnecessary off-route times are considered together because they must be distributed equally over the entire operation.

Necessary off-route time includes (1) time spent checking in and out in the morning and at the end of the day, (2) time lost due to unavoidable congestion, and (3) time spent on equipment repairs, maintenance, and so on. Unnecessary off-route time includes time spent for lunch in excess of the stated lunch period and time spent on taking unauthorized coffee breaks, talking to friends, and the like.

Hauled Container Systems

The time required per trip, which also corresponds to the time required per container, is equal to the sum of the pickup, at-site, and haul time and is given by the following equation:

$$T_{hcs} = (P_{hcs} + s + h) \tag{8-1}$$

where T_{hcs} = time per trip for hauled container system, h/trip
P_{hcs} = pickup time per trip for hauled container system, h/trip
s = at-site time per trip, h/trip
h = haul time per trip, h/trip

For hauled container systems the pickup and at-site times are relatively constant, but the haul time depends on both haul speed and distance. From an analysis of a considerable amount of haul data for various types of collection vehicles (see Fig. 8-16), it has been found [5, 7] that the haul time h may be approximated by the following expression:

$$h = a + bx \tag{8-2}$$

where h = total haul time, h/trip
a = empirical haul-time constant, h/trip
b = empirical haul-time constant, h/mi
x = average round-trip haul distance, mi/trip

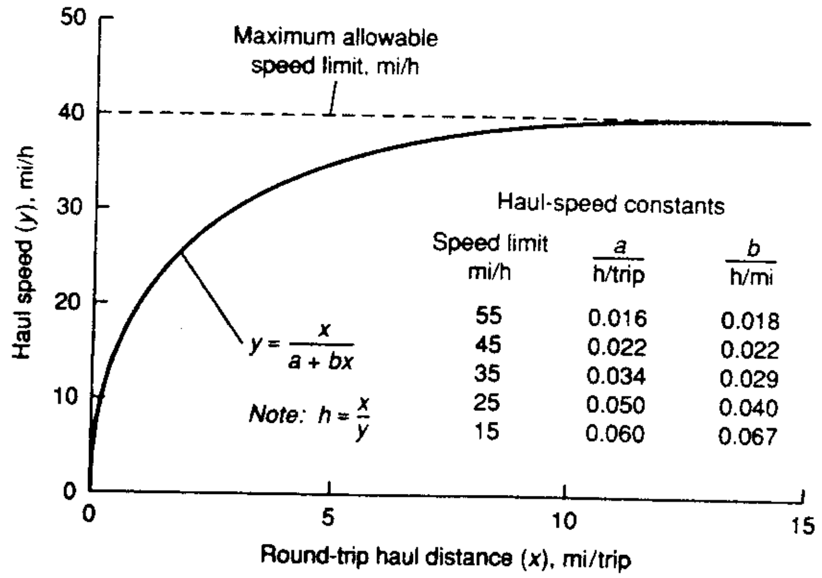


FIGURE 8-16
Correlation between average haul speed and round-trip haul distance for waste collection vehicles [6].

For places where a number of pickup locations are located in a given service area, the average round-trip haul distance from the center of gravity of the service area to the disposal site can be used in Eq. (8-2). Determination of the haul-time constants is illustrated in Example 8-2, presented at the end of this discussion.

Substituting in Eq. (8-1) the expression for h given in Eq. (8-2), the time per trip can be expressed as follows:

$$T_{\text{hcs}} = (P_{\text{hcs}} + s + a + bx) \tag{8-3}$$

The pickup time per trip, P_{hcs}, for the hauled container system is equal to

$$P_{\text{hcs}} = \text{pc} + \text{uc} + \text{dbc} \tag{8-4}$$

where P_{hcs} = pickup time per trip, h/trip
pc = time required to pick up loaded container, h/trip
uc = time required to unload empty container, h/trip
dbc = time required to drive between container locations, h/trip

If the average time required to drive between containers is unknown, the time can be estimated by using Eq. (8-2). The distance between containers is substituted for the round-trip haul distance and the haul-time constants for 15 mi/h (see Fig. 8-16) should be used.

The number of trips that can be made per vehicle per day with a hauled container system, taking into account the off-route factor W, can be determined by using Eq. (8-5):

$$N_d = [H(1 - W) - (t_1 + t_2)]/T_{\text{hcs}} \tag{8-5}$$

where N_d = number of trips per day, trips/d
H = length of work day, h/d
W = off-route factor, expressed as a fraction

t_1 = time to drive from dispatch station (garage) to first container location to be serviced for the day, h
t_2 = time to drive from the last container location to be serviced for the day to the dispatch station (garage), h
T_{hcs} = pickup time per trip, h/trip

In deriving Eq. (8-5), it is assumed that off-route activities can occur at any time during the day. Data that can be used in the solution of Eq. (8-5) for various types of hauled container systems are given in Fig. 8-16 and Table 8-5. The off-route factor in Eq. (8-5) varies from 0.10 to 0.40; a factor of 0.15 is representative for most operations. Application of Eqs. (8-3) through (8-5) is illustrated in Example 8-2.

The number of trips that can be made per day, computed from Eq. (8-5), can be compared with the number of trips required per day (or week), which can be computed using the following expression:

$$N_d = V_d/(cf) \tag{8-6}$$

where N_d = number of trips per day, trips/d
V_d = average daily quantity of waste collected, yd^3/d
c = average container size, $yd^3/trip$
f = weighted average container utilization factor

As noted previously, the container utilization factor may be defined as the fraction of the container volume occupied by solid wastes. Because this factor will vary with the size of the container, a weighted container utilization factor is used in Eq. (8-6). The weighted factor is found by dividing the sum of the values obtained by multiplying the number of containers in each size by their corresponding utilization factor by the total number of containers.

TABLE 8-5
Representative data to use for computing equipment and labor requirements for various collection systems[a]

Collection data					
Vehicle	Loading method	Compaction ratio, r	Time required to pick up loaded container and to deposit empty container, h/trip	Time required to empty contents of loaded container, h/container	At-site time, h/trip
Hauled container system					
Hoist truck	Mechanical	—	0.067		0.053
Tilt-frame	Mechanical	—	0.40		0.127
Tilt-frame	Mechanical	2.0–4.0[a]	0.40		0.133
Stationary container system					
Compactor	Mechanical	2.0–2.5		0.008–0.05[b]	0.10
Compactor	Manual	2.0–2.5		—	0.10

[a] Containers used in conjunction with stationary compactor.
[b] Time required varies depending on the size of the container.

Example 8-2 Determination of haul-speed constants. The following average speeds were obtained for various round-trip distances to a disposal site (see Comment statement at end of problem). Find the haul-speed constants a and b and the round-trip haul time for a site that is located 11.0 mi away.

Round-trip distance (x), mi/trip	Average haul speed (y), mi/h	Total time ($h = x/y$), h
2	17	0.12
5	28	0.18
8	32	0.25
12	36	0.33
16	40	0.40
20	42	0.48
25	45	0.56

Solution

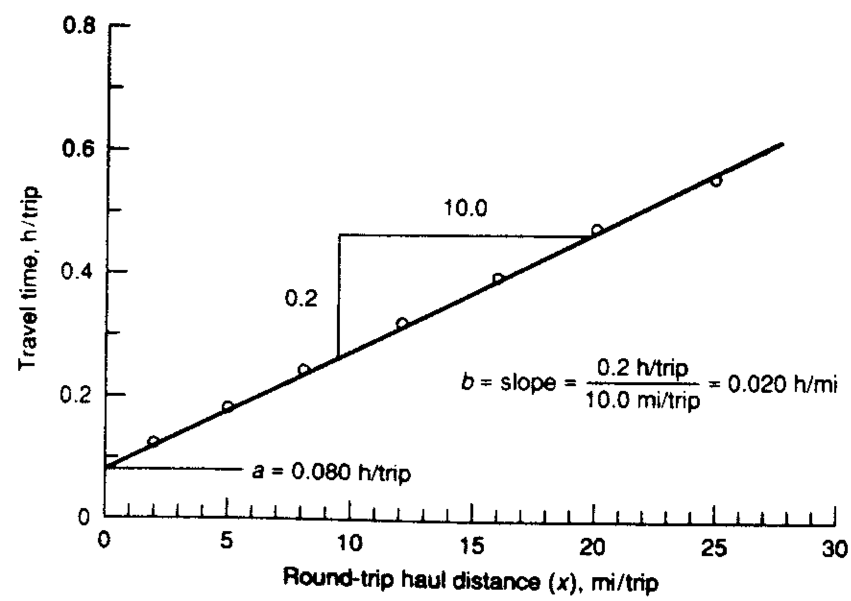
1. Linearize the haul-speed equation given in Fig. 8-16. The basis haul-speed equation (a rectangular hyperbola) is

$$y = \frac{x}{a + bx}$$

The linearized form of this equation is

$$\frac{x}{y} = h = a + bx$$

2. Plot x/y, which is the total haul travel time versus the round-trip distance as shown below.



3. Determine the haul-time constants a and b. When $x = 0$, a = intercept value = 0.080 h/trip, b = slope of line = (0.2 h/trip)/(10 mi/trip) = 0.020 h/mi (0.012 h/km).

4. Find the round-trip haul time for a site that is located 11.0 mi away.

$$\text{Round-trip distance} = 2(11.0 \text{ mi/trip}) = 22 \text{ mi/trip}$$

$$\text{Round-trip haul time } h = a + bx$$

$$= 0.080 \text{ h/trip} + (0.020 \text{ h/mi})(22 \text{ mi/trip})$$

$$= 0.52 \text{ h/trip}$$

Comment. When determining the time required to travel to the disposal site in the field the times should be determined at approximately the same times the collection vehicles will be traveling to and from the unloading location. Haul time data collected during working hours will include the effects of traffic congestion, weather conditions, and so on.

Example 8-3 Analysis of a hauled container system. Solid waste from a new industrial park is to be collected in large containers (drop boxes), some of which will be used in conjunction with stationary compactors. Based on traffic studies at similar parks, it is estimated that the average time to drive from the garage to the first container location (t_1) and from the last container location (t_2) to the garage each day will be 15 and 20 min, respectively. If the average time required to drive between containers is 6 min and the one-way distance to the disposal site is 15.5 mi (speed limit: 55 mi/h), determine the number of containers that can be emptied per day, based on an 8-h workday. Assume the off-route factor, W, is equal to 0.15.

Solution

1. Determine the pickup time per trip using Eq. (8-4).

$$P_{hcs} = \text{pc} + \text{uc} + \text{dbc}$$

Use pc + uc = 0.4 h/trip (see Table 8-5)

$$\text{dbc} = 0.1 \text{ h/trip (given)}$$

$$P_{hcs} = (0.4 + 0.1) \text{ h/trip}$$

$$= (0.4 + 0.1) \text{ h/trip}$$

$$= 0.5 \text{ h/trip}$$

2. Determine the time per trip using Eq. (8-3).

$$T_{hcs} = (P_{hcs} + s + a + bx)$$

$$P_{hcs} = 0.5 \text{ h/trip (from Step 1)}$$

$$s = 0.133 \text{ h/trip (see Table 8-5)}$$

$$a = 0.016 \text{ h/trip (see Fig. 8-16)}$$

$$b = 0.018 \text{ h/trip (see Fig. 8-16)}$$

$$T_{hcs} = [0.5 + 0.133 + 0.016 + 0.018(31)] \text{ h/trip}$$

$$= 1.21 \text{ h/trip}$$

3. Determine the number of trips that can be made per day using Eq. (8-5).

$$N_d = [H(1 - W) - (t_1 + t_2)]/T_{hcs}$$

$$\text{Use } H = 8 \text{ h (given)}$$

$$W = 0.15 \text{ (assumed)}$$

$$t_1 = 0.25 \text{ h (given)}$$

$$t_2 = 0.33 \text{ h (given)}$$

$$T_{hcs} = 1.21 \text{ h/trip}$$

$$N_d = [8(1 - 0.15) - (0.25 + 0.33)]/(1.21 \text{ h/trip})$$

$$= (6.8 - 0.58)/(1.21 \text{ h/trip})$$

$$= 5.14 \text{ trips/d}$$

$$\text{Use } N_d = 5.0 \text{ trips/d}$$

4. Determine the actual length of the workday.

$$5 \text{ trips/d} = [H(1 - 0.15) - 0.58]/(1.21 \text{ h/trip})$$

$$H = 7.80 \text{ h (essentially 8 h)}$$

Comment. Where fractional equipment and labor requirements are obtained, the use of large containers and reduced collection frequency should be investigated. If it is assumed that no off-route activities occur during times t_1 and t_2, then theoretically 5.21 trips/d could be made. Again, only 5 trips/d would be made in an actual operation. If, however, the number of trips per day that could be made were 5.8, for example, it may be cost-effective to pay the driver for the overtime and make 6 trips/d.

Stationary Container Systems

Because of differences in the loading processes, mechanically and manually loaded stationary container systems are considered separately in the following discussion.

Mechanically Loaded Collection Vehicles. For systems using self-loading collection vehicles, the time per trip is expressed as

$$T_{scs} = (P_{scs} + s + a + bx) \tag{8-7}$$

where T_{scs} = time per trip for stationary container system, h/trip
P_{scs} = pickup time per trip for stationary container system, h/trip
s = at-site time per trip, h/trip
a = empirical constant, h/trip
b = empirical constant, h/mi
x = average round-trip haul distance, mi/trip

As with the hauled container system, if no other information is available the average round-trip distance from the center of gravity of the service area to the disposal site can be used in Eq. (8-7).

The only difference between Eq. (8-7) and Eq. (8-3) for hauled container systems is the pickup term. For the stationary container system, the pickup time is given by

$$P_{scs} = C_t(\text{uc}) + (n_p - 1)(\text{dbc}) \tag{8-8}$$

where P_{scs} = pickup time per trip for stationary container system, h/trip
C_t = number of containers emptied per trip, containers/trip
uc = average unloading time per stationary container for stationary container systems, h/container
n_p = number of container pickup locations per trip, locations/trip
dbc = average time spent driving between container locations, h/location

The term $(n_p - 1)$ accounts for the fact that the number of times the collection vehicle will have to be driven between container locations is equal to the number of container locations less 1. As in the case of the hauled container system, if the time spent driving between container locations is unknown, it can be estimated by using Eq. (8-2) where the distance between containers is substituted for the round-trip haul distance and the haul-time constants for 15 mi/h (see Fig. 8-16) are used.

The number of containers that can be emptied per collection trip is related directly to the volume of the collection vehicle and the compaction ratio that can be achieved. This number is given by

$$C_t = vr/cf \tag{8-9}$$

where C_t = number of containers emptied per trip, containers/trip
v = volume of collection vehicle, yd^3/trip
r = compaction ratio
c = container volume, yd^3/container
f = weighted container utilization factor

The number of trips required per day can be estimated by using the following equation:

$$N_d = V_d/vr \tag{8-10}$$

where N_d = number of collection trips required per day, trips/d
V_d = average daily quantity of waste collected, yd^3/d

The time required per day, taking into account the off-route factor W, can be expressed as follows:

$$H = [(t_1 + t_2) + N_d(T_{scs})]/(1 - W) \tag{8-11}$$

where t_1 = time to drive from dispatch station (garage) to the location of the first container to be picked up on the first route of the day, h
t_2 = time to drive from the approximate location of the last container pickup on last route of the day to the dispatch station (garage), h
other terms = as defined previously

In defining t_2, the term *approximate location* is used because in the stationary container system, the collection vehicle is normally driven directly back to the dispatch station after the wastes collected on the last route have been emptied. If the travel time from the disposal site (or transfer point) to the dispatch station is less than one half the average round-trip haul time, t_2 is assumed to be equal to zero. If the travel time from the disposal site (or transfer point) to the dispatch station is greater than the travel time from the last pickup location to the disposal site, the time t_2 is assumed to be equal to the difference between the time to drive to the dispatch station from the disposal site and one half the average round-trip haul time.

Where an integer number of trips are to be made each day, the proper combination of trips per day and the size of the vehicle can be determined by using Eq. (8-11) in conjunction with an economic analysis. To determine the required truck volume, substitute two or three different values for N_d in Eq. (8-11) and determine the available pickup times per trip. Then, by successive trials, using Eqs. (8-8) and (8-9), determine the truck volume required for each value of N_d. From the available truck sizes, select the ones that most nearly correspond to the computed values. If available truck sizes are smaller than the required values, compute the actual time per day that will be required using these sizes. The most cost-effective combination can then be selected. The application of the above equations is illustrated in Example 8-3.

When the truck size is fixed and an integer number of trips must be made each day, the length of the required workday can be estimated using Eqs. (8-8), (8-9), and (8-11). A hauled and a stationary container system are analyzed and compared in Example 8-4.

Once the labor requirements for each combination of truck size and number of trips per day have been determined, the most cost-effective combination can be selected. For example, where long haul distances are involved, it may be more economical to use a large collection vehicle and make two trips/day (even though some time at the end of the day may not be used) than to use a smaller vehicle and make three trips/day by using all the available time.

Example 8-4 Comparison between the hauled container and stationary container systems. A private solid waste collector wishes to locate a MRF near a commercial area. The collector would like to use a hauled container system but fears that the haul costs might be prohibitive. What is the maximum distance away from the commercial area that the MRF can be located so that the weekly costs of the hauled container system do not exceed those of a stationary container system? Assume that one collector-driver will be used with each system and that the following data are applicable. For the purpose of this example assume the travel times t_1 and t_2 are included in the off-route factor.

1. **Hauled container system**
   - (*a*) Quantity of solid wastes = 300 yd^3/wk
   - (*b*) Container size = 8 yd^3/trip
   - (*c*) Container utilization factor = 0.67

(*d*) Container pickup time = 0.033 h/trip
(*e*) Container unloading time = 0.033 h/trip
(*f*) Haul-time constants: a = 0.022 h/trip and b = 0.022 h/mi
(*g*) At-site time = 0.053 h/trip
(*h*) Overhead costs = \$400/wk
(*i*) Operational costs = \$15/h of operation

2. Stationary container system
   (*a*) Quantity of solid wastes = 300 yd^3/wk
   (*b*) Container size = 8 yd^3/location
   (*c*) Container utilization factor = 0.67
   (*d*) Collection vehicle capacity = 30 yd^3/trip
   (*e*) Collection vehicle compaction ratio = 2
   (*f*) Container unloading time = 0.05 h/container
   (*g*) Haul-time constants: a = 0.022 h/trip and b = 0.022 h/mi
   (*h*) At-site time = 0.10 h/trip
   (*i*) Overhead costs = \$750/wk
   (*j*) Operational costs = \$20/h of operation
3. Location characteristics
   (*a*) Average distance between container locations = 0.1 mi
   (*b*) Constants for estimating driving time between container locations for both the hauled container and stationary container systems are a' = 0.060 h/trip and b' = 0.067 h/mi

Solution

1. Hauled container system
   (*a*) Determine the number of trips per week, using Eq. (8-6).

$$N_w = V_w/cf = (300\ \text{yd}^3/\text{wk})/(8\text{yd}^3/\text{trip})(0.67)$$
$$= 56.0\ \text{trips/wk}$$

   (*b*) Estimate the average pickup time for the hauled container system, using Eq. (8-4).

$$P_{\text{hcs}} = \text{pc} + \text{uc} + \text{dbc} = \text{pc} + \text{uc} + a' + b'x'$$
$$= 0.033\ \text{h/trip} + 0.033\ \text{h/trip} + 0.060\ \text{h/trip}$$
$$+ (0.067\ \text{h/mi})(0.1\ \text{mi/trip})$$
$$= 0.133\ \text{h/trip}$$

   (*c*) Estimate the time required per week, T_w, as a function of the round-trip haul distance, using the following expression.

$$T_w = N_w(P_{\text{hcs}} + s + a + bx)/[H(1 - W)]$$
$$T_w = (56\ \text{trips/wk})[0.133\ \text{h/trip} + 0.053\ \text{h/trip} + 0.022\ \text{h/trip}$$
$$+ (0.022\ \text{h/mi})(x)]/[(8\ \text{h/d})(1 - 0.15)]$$
$$= [1.71 + (0.181/\text{mi})(x)]\ \text{d/wk}$$

(*d*) Determine the weekly operational cost as a function of the round-trip haul distance.

$$\text{Operational cost} = (\$15/\text{h})(8\ \text{h/d})[1.71 + (0.181/\text{mi})(x)]\ \text{d/wk}$$
$$= [205.20 + (21.7/\text{mi})(x)]\ \$/\text{wk}$$

2. Stationary container system

(*a*) Determine the number of containers emptied per trip, using Eq. (8-9).

$$C_t = vr/cf = (30\ \text{yd}^3/\text{trip})(2)/(8\ \text{yd}^3/\text{container})(0.67)$$
$$= 11.19\ \text{containers/trip} = 11\ \text{containers/trip}$$

(*b*) Estimate the pickup time per container by using Eq. (8-8).

$$P_{scs} = C_t(\text{uc}) + (n_p - 1)(\text{dbc})$$
$$= C_t(\text{uc}) + (n_p - 1)(a' + b'x')$$
$$= (11\ \text{containers/trip})(0.050\ \text{h/container})$$
$$+ (11 - 1\ \text{locations/trip})[(0.06\ \text{h/locations})$$
$$+ (0.067\ \text{h/mi})(0.1\ \text{mi/location})]$$
$$= 1.22\ \text{h/trip}$$

(*c*) Determine the number of trips required per week by using Eq. (8-10).

$$N_w = V_w/vr = (300\ \text{yd}^3/\text{wk})/(30\ \text{yd}^3/\text{trip})(2)$$
$$= 5\ \text{trips/wk}$$

(*d*) Determine the time required per week, T_w, as a function of the round-trip haul distance using the following expression. The term T_w represents the integer number of trips made to the location where the contents of the collection vehicle will be unloaded. The numerical value of T_w is obtained by rounding up the value of N_w to an integer value.

$$T_{w(scs)} = [(N_w)P_{scs} + t_w(s + a + bx)]/[H(1 - W)]$$
$$= \{(5\ \text{trips/wk})(1.22\ \text{h/trip}) + (5\ \text{trips/wk})$$
$$\times [0.10\ \text{h/trip} + 0.022\ \text{h/trip} + (0.022\ \text{h/mi})(x)]\}$$
$$/[(8\ \text{h/d})(1 - 0.15)]$$
$$= [0.99 + (0.016/\text{mi})(x)]\ \text{d/wk}$$

(*e*) Determine the weekly operational costs as a function of the round-trip haul distance.

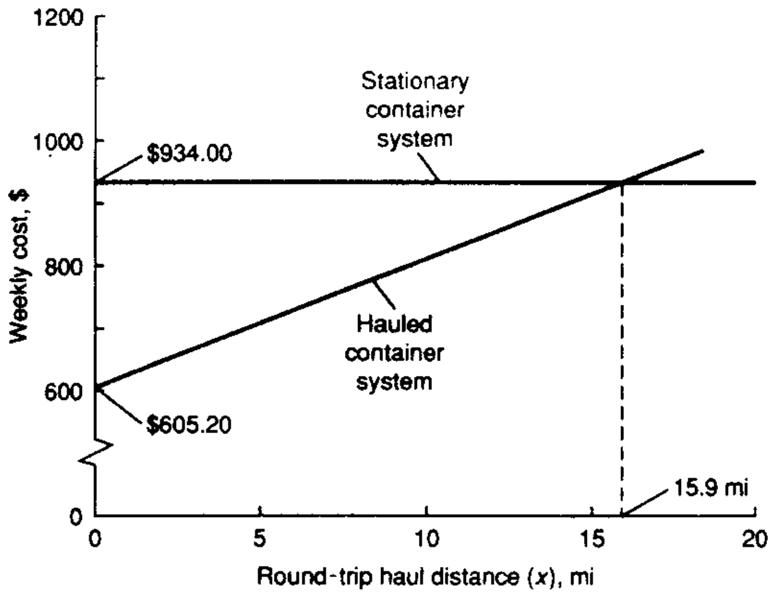
$$\text{Operational cost} = (\$20/\text{h})(8\ \text{h/d}) \times [0.99 + (0.016/\text{mi})(x)]\ \text{d/wk}$$
$$= [158.40 + (2.56/\text{mi})(x)]\ \$/\text{wk}$$

3. Comparison of systems

(*a*) Determine the maximum round-trip haul distance at which the cost for hauled container systems equals the cost for the stationary container systems by equating the total costs for the two systems and solving for x.

$$\$400/\text{wk} + [205.20 + (21.7/\text{mi})(x)]\ \$/\text{wk} = \$750/\text{wk}$$
$$+[158.40 + (2.56/\text{mi})(x)]\ \$/\text{wk}$$
$$(19.1/\text{mi})(x) = 303.20$$
$$x = 15.9\ \text{mi (one-way distance} \sim 8.0\ \text{mi)}$$

(*b*) Plot the weekly cost versus round-trip haul distance for each system. The required plot is presented below.



Comment. The curves shown in the figure given above are characteristic of those obtained when hauled container systems are compared with stationary container systems. In most cases the round-trip haul distance at which hauled container systems are no longer competitive is much shorter than in this example.

Manually Loaded Vehicles. The analysis and design of residential collection systems using manually loaded vehicles may be outlined as follows. If H hours are worked per day and the number of trips to be made per day is known or fixed, the time available for the pickup operation can be computed by using Eq. (8-11) because either all the factors are known or they can be assumed. Once the pickup time per trip is known, the number of pickup locations from which wastes can be collected per trip can be estimated as follows:

$$N_p = 60 P_{scs} n / t_p \qquad (8\text{-}12)$$

where N_p = number of pickup locations per trip, locations/trip
60 = conversion factor from hours to minutes, 60 min/h
P_{scs} = pickup time per trip, h/trip
n = number of collectors, collectors
t_p = pickup time per pickup location, collector-min/location

The pickup time t_p per location depends on the time required to drive between container locations, the number of containers per pickup location, and the percent of rear-of-house pickup locations. The corresponding relationship is

$$t_p = \text{dbc} + k_1 C_n + k_2(\text{PRH}) \tag{8-13}$$

where t_p = average pickup time per pickup location, collector-min/location
dbc = average time spent driving between container locations, h/location
k_1 = constant related to the pickup time per container, min/container
C_n = average number of containers at each pickup location
k_2 = constant related to the time required to collect waste from the backyard of a residence, min/PRH
PRH = rear-of-house pickup locations, percent

Equation (8-13) is typical of the types of equations derived from field observations for the pickup time per location. The time spent driving between pickup locations will, of course, depend on the characteristics of the residential area. Typical pickup-time data derived from field observations for a two-person collection crew are reported in Fig. 8-17. If once-per-week curb collection service is provided, the data in Table 8-5 may be used to estimate the labor requirements.

The data reported in Table 8-6 for a one-person crew are based on the use of a side-loaded collection vehicle equipped with a standup drive [6] (see Fig. 8-1*a*). If conventional trucks are used for curb collection, the pickup time per service reported in Table 8-6 should be increased by 5 to 10 percent. Although Eq. (8-13) and the data in Table 8-6 can be used to estimate the time per pickup

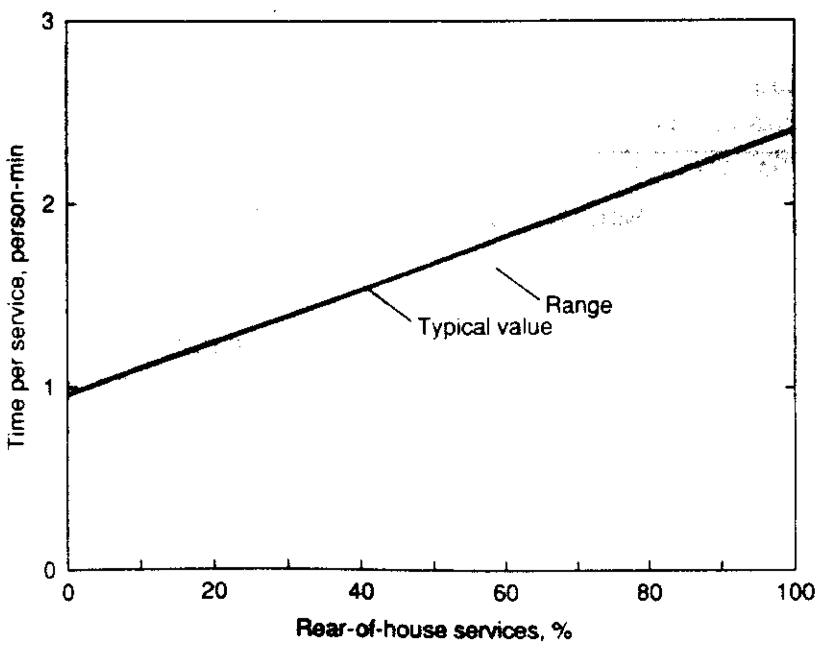


FIGURE 8-17
Relationship between time requirements for pickup and percent of rear-of-house services for a two-person crew [6].

TABLE 8-6
Labor requirements for manual curbside collection using a one-person crew

Average number of containers and/or boxes per pickup location	Pickup time, collector · min/location
1 or 2	0.50–0.60
3 or more, or unlimited service	0.92

location, it is recommended that field measurements be made whenever possible because residential collection operations are so variable. The use of Eq. (8-13) is illustrated in Example 8-5.

Once the number of pickup locations per trip is known, the proper size of collection vehicle can then be estimated as follows:

$$v = V_p N_p / r \tag{8-14}$$

where v = volume of collection vehicle, yd^3/trip
V_p = volume of solid wastes collected per pickup location, yd^3/location
N_p = number of pickup locations per trip, locations/trip
r = compaction ratio

In many housing areas, the collection frequency is twice per week. The effect of twice-per-week collection on the amount of wastes collected was discussed in Chapter 6. In terms of labor requirements, it has been found that the requirements for the second weekly collection are about 0.9 and 0.95 times those of the first weekly collection. In general, the labor requirements are not significantly different, because container handling time is about the same for both full and partly full containers. Often this difference is neglected in computing the labor requirements.

Example 8-5 Design of residential collection system. Design a solid waste curb collection system to service a residential area with 1000 single-family dwellings. Two manually loaded collection systems are to be evaluated. The first involves the use of a side-loaded collection vehicle with a one-person crew; the second involves the use of a rear-loaded collection vehicle with a two-person crew. Determine the size of collection vehicle required and compare the labor requirements for each collection system. Assume the following data are applicable:

1. Average number of residents per service = 3.5
2. Solid waste generation rate per capita = 2.5 lb/capita · d
3. Density of solid wastes (at containers) = 200 lb/yd^3
4. Containers per service = two 32-gal containers plus 1.5 cardboard containers (20 gal on average)
5. Collection frequency = once per week

6. Collection vehicle compaction ratio, $r = 2.5$
7. Round-trip haul distance, $h = 35$ mi
8. Nominal length of workday, $H = 8$ h
9. Trips per day, $N_d = 2$
10. Travel time to first pickup location, $t_1 = 0.3$ h
11. Travel time from last pickup location, $t_2 = 0.4$ h
12. Off-route factor, $W = 0.15$
13. Haul-time constants: $a = 0.016$ h/trip and $b = 0.018$ mi/h
14. At-site time per trip, $s = 0.10$ h/trip

Solution

1. Determine the time available for the pickup operation using Eq. (8-11). Substituting Eq. (8-7) for the term T_{scs} in Eq. (8-11) yields

$$H = [(t_1 + t_2) + N_d(P_{scs} + s + a + bx)]/(1 - W)$$

$$\begin{aligned}P_{scs} &= [H(1 - W) - (t_1 + t_2)]/N_d - (s + a + bx)\\ &= [(8 \text{ h/day})(1 - 0.15) - (0.3 \text{ h/day} + 0.4 \text{ h/day})]/(2 \text{ trips/day})\\ &\quad - [0.10 \text{ h/trip} + 0.016 \text{ h/trip} + (0.018 \text{ h/mi})(35 \text{ mi/trip})]\\ &= (3.05 - 0.75) \text{ h/trip}\\ &= 2.30 \text{ h/trip}\end{aligned}$$

2. Determine the pickup time required per pickup location using Eq. (8-13).
   (*a*) One-person crew

$$t_p = 0.92 \text{ min/location (see Table 8-6)}$$

   (*b*) Two-person crew

$$\begin{aligned}t_p &= 0.72 + 0.18(C_n)\\ &= 0.72 + 0.18(3.5)\\ &= 1.35 \text{ collector-min/location}\end{aligned}$$

3. Determine the number of pickup locations from which wastes can be collected, using Eq. (8-12).
   (*a*) One-person crew

$$\begin{aligned}N_p &= 60P_{scs}n/t_p\\ &= (60 \text{ min/h})(2.30 \text{ h/trip})(1 \text{ collector})/(0.92 \text{ collector-min/location})\\ &= 150 \text{ locations/trip}\end{aligned}$$

   (*b*) Two-person crew

$$\begin{aligned}N_p &= 60P_{scs}n/t_p\\ &= (60 \text{ min/h})(2.30 \text{ h/trip})(2 \text{ collector})/(1.35 \text{ collector-min/location})\\ &= 204 \text{ locations/trip}\end{aligned}$$

4. Determine the volume of wastes generated per pickup location per week.

$$\text{Volume per week per location} = (2.5\ \text{lb/person/day})(3.5\ \text{persons/pickup location})(7\ \text{days/wk})/(200\ \text{lb/yd}^3)(1/\text{wk})$$
$$= 0.306\ \text{yd}^3/\text{location}$$

5. Determine the required truck volume using Eq. (8-14).
   (*a*) One-person crew

$$v = V_p N_p / r$$
$$= (0.306\ \text{yd}^3/\text{location})(150\ \text{locations/trip})/2.5$$
$$= 18.4\ \text{yd}^3/\text{trip (use an 18 yd}^3\text{ collection vehicle)}$$

   (*b*) Two-person crew

$$v = V_p N_p / r$$
$$= (0.306\ \text{yd}^3/\text{location})(204\ \text{locations/trip})/2.5$$
$$= 25.0\ \text{yd}^3/\text{trip (use a 25 yd}^3\text{ collection vehicle or nearest standard size, if available)}$$

6. Determine the number of trips required per week.
   (*a*) One-person crew

$$N_w = (1000\ \text{locations})(1/\text{wk})/(150\ \text{locations/trip})$$
$$= 6.67\ \text{trips/wk}$$

   (*b*) Two-person crew

$$N_w = (1000\ \text{locations})(1/\text{wk})/(204\ \text{locations/trip})$$
$$= 4.90\ \text{trips/wk}$$

7. Determine the labor requirements. Note that even though a partial trip is computed, a full trip will have to be made to the location where the contents of the collection vehicle will be unloaded.
   (*a*) One-person crew

$$1.0\ \text{collector}\{(6.67\ \text{trips/wk})(2.3\ \text{h/trip}) + (7\ \text{trips/wk})[0.10\ \text{h/trip} + 0.016\ \text{h/trip} + (0.018\ \text{h/mi})(35\ \text{mi/trip})]\}/(1 - 0.15)(8\ \text{h/day})$$
$$= 3.02\ \text{collector-day/wk}$$

   (*b*) Two-person crew

$$2.0\ \text{collectors}\{(4.9\ \text{trips/wk})(2.3\ \text{h/trip}) + (5\ \text{trips/wk})[0.10\ \text{h/trip} + 0.016\ \text{h/trip} + (0.018\ \text{h/mi})(35\ \text{mi/trip})]\}/(1 - 0.15)(8\ \text{h/day})$$
$$= 4.41\ \text{collector-day/wk}$$

Comment. As determined in this problem, the labor requirements for the one-person crew are approximately 25 percent less than corresponding requirements for the two-person collection crew. The results of this example illustrate why the trend in collection is towards the use of curb collection with one collector-driver and collection vehicles that are either manually or mechanically loaded.

8-4 COLLECTION ROUTES

Once equipment and labor requirements have been determined, collection routes must be laid out so that both the collectors and equipment are used effectively. In general, the layout of collection routes involves a series of trials. There is no universal set of rules that can be applied to all situations. Thus, collection vehicle routing remains today a heuristic (common sense) process [4].

Some heuristic guidelines that should be taken into consideration when laying out routes are as follows:

1. Existing policies and regulations related to such items as the point of collection and frequency of collection must be identified.
2. Existing system characteristics such as crew size and vehicle types must be coordinated.
3. Wherever possible, routes should be laid out so that they begin and end near arterial streets, using topographical and physical barriers as route boundaries.
4. In hilly area, routes should start at the top of the grade and proceed downhill as the vehicle becomes loaded.
5. Routes should be laid out so that the last container to be collected on the route is located nearest to the disposal site.
6. Wastes generated at traffic-congested locations should be collected as early in the day as possible.
7. Sources at which extremely large quantities of wastes are generated should be serviced during the first part of the day.
8. Scattered pickup points (where small quantities of solid waste are generated) that receive the same collection frequency should, if possible, be serviced during one trip or on the same day.

Layout of Collection Routes

The general steps involved in establishing collection routes include (1) preparation of location maps showing pertinent data and information concerning the waste generation sources, (2) data analysis and, as required, preparation of information summary tables, (3) preliminary layout of routes, and (4) evaluation of the preliminary routes and the development of balanced routes by successive trials. Step 1, as discussed below, is essentially the same for all types of collection systems. Because the application of Steps 2, 3, and 4 is different for the hauled and stationary container systems, each is discussed separately. The layout of collection routes is illustrated in Examples 8-5 and 8-6.

Note that the balanced routes prepared in the office (Step 4) are given to the collector-drivers, who implement them in the field. Based on the field experience of the collector-driver, each route is modified to account for specific local conditions. In large municipalities, route supervisors are responsible for the preparation of collection routes. In most cases, the routes are based on the operating experience of the route supervisor, gained over a period of years working in the same section of the city. The following discussion is designed to quantify on paper what most route supervisors do in their heads.

Collection Route Layout—Step 1. On a relatively large-scale map of the commercial, industrial, or residential housing area to be served, the following data should be plotted for each solid waste pickup point: location, collection frequency, number of containers. If a mechanically loaded stationary container system is used for commercial and industrial services, the estimated quantity of wastes to be collected at each pickup location should also be entered on the map. For residential sources it is generally assumed that approximately the same average quantity of waste will be collected from each source. Often, for residential sources only the number of homes per block will be shown.

Because the layout of collection routes involves a series of successive trials, tracing paper should be used once the basic data have been entered on the work map. Depending on the size of the area and the number of pickup points, the area should be subdivided into areas corresponding roughly to similar land-use areas (e.g., residential, commercial, industrial). For locations with less than 20 to 30 pickup points, this step is usually not necessary. For larger areas it may be necessary to subdivide further each of the similar land-use areas into smaller areas, taking into account factors such as waste generation rates and collection frequency.

Collection Route Layout—Steps 2, 3, and 4 for Hauled Container Systems. Steps 2, 3, and 4 for the hauled container system can be outlined as follows.

Step 2. On a spreadsheet program first enter the following headings: collection frequency, times/wk; number of pickup locations; total number of containers; number of trips, trips/wk; and a separate column for each day of the week during which wastes will be collected. Second, determine the number of pickup locations requiring multiple pickups during the week (e.g., Monday through Friday or Monday, Wednesday, Friday) and enter the information on the spreadsheet. Start the listing with the locations requiring the highest number of pickups per week (e.g., 5 times/wk). Third, distribute the number of containers requiring once per week service so that the number of containers emptied per day is balanced for each collection day. Preliminary collection routes can be laid out once this information is known.

Step 3. Using the information from Step 2, the layout of collection routes can be outlined as follows. Starting from the dispatch station (or where the collection vehicles are parked), a route should be laid out that connects all the pickup points (containers) to be serviced during each collection day. The next step is to modify the basic route to include the additional containers that will be serviced on each collection day. Each daily route should be laid out so it begins and ends near the dispatch station. The collection operation should proceed in a logical manner, taking into account the guidelines cited previously and specific local constraints.

Step 4. When preliminary routes have been laid out, the average distance to be traveled between containers should be computed. If the routes are unbalanced with respect to the distance traveled (> 15 percent), they should be redesigned so that each route covers approximately the same distance. In general, a number of collection routes must be tried before the final ones are selected. When more than one collection vehicle is required, collection routes for each functional-use or service area must be laid out, and work loads for each driver must be balanced.

Collection Route Layout—Steps 2, 3, and 4 for Stationary Container System (with Mechanically Loaded Collection Vehicles). Steps 2, 3, and 4 for stationary container systems that are loaded mechanically can be outlined as follows.

Step 2. On a spreadsheet program first enter the following heads: collection frequency, times/wk; number of pickup locations; total waste, yd^3/wk; and a separate column for each day of the week during which wastes will be collected. Second, determine the amount of waste to be collected from pickup locations requiring multiple pickups during the week (e.g., Monday through Friday or Monday, Wednesday, Friday) and enter the information on the spreadsheet. Start the listing with the locations requiring the highest number of pickups per week (e.g., 5 times/wk). Third, using the effective volume of the collection vehicle (nominal collection vehicle volume × compaction ratio), determine the amount of additional waste that can be collected each day from locations receiving once per week service. Distribute the amount of waste collected so that the amount of waste collected (and the number of containers emptied) per trip is balanced for each collection route. Preliminary collection routes can be laid out once this information is known.

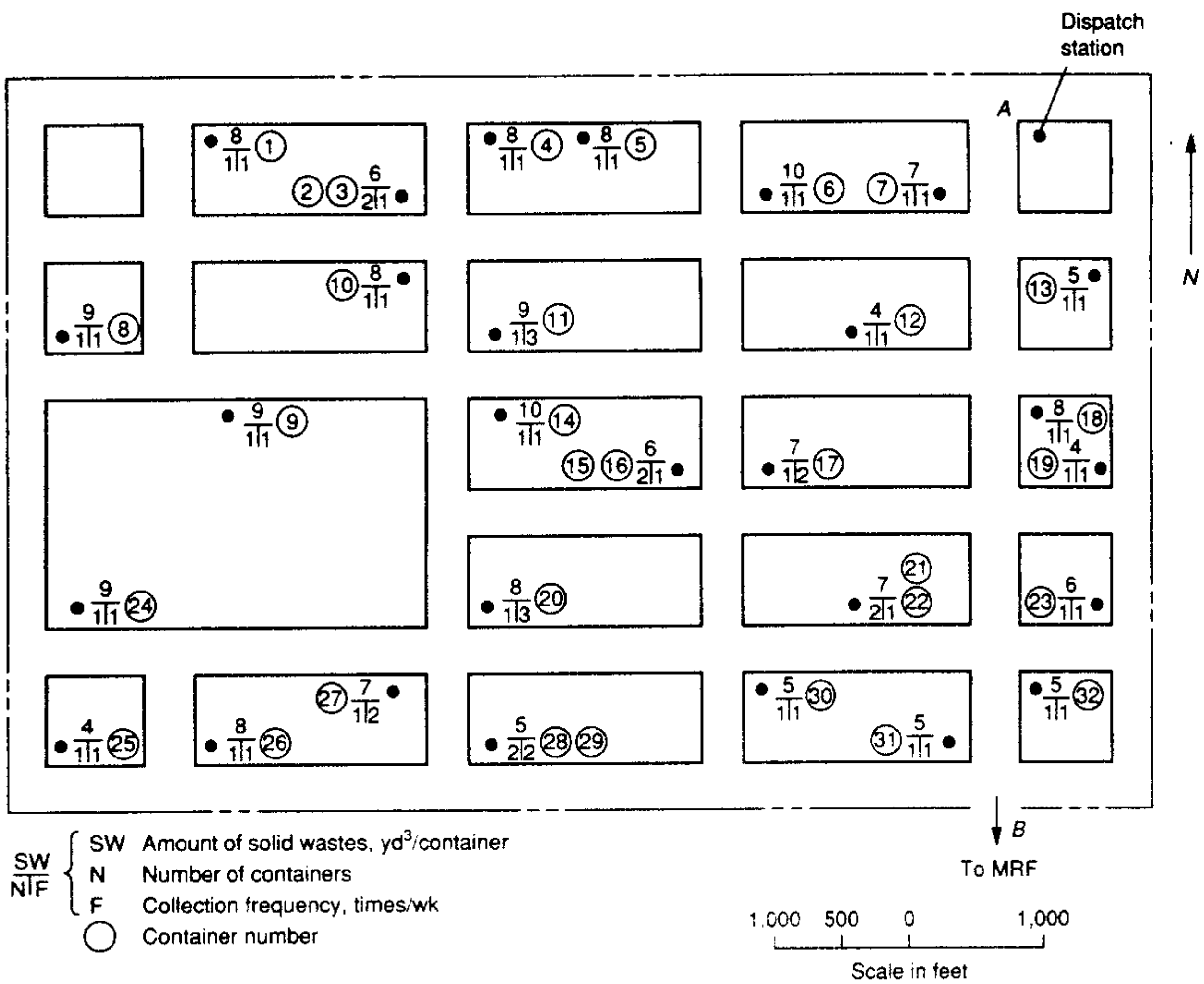
Step 3. Once the foregoing information is known, the layout of collection routes can proceed as follows. Starting from the dispatch station (or where the collection vehicles are parked), a route should be laid out that connects all the pickup points to be serviced during each collection day. Depending on the quantity of waste to be collected, several basic routes may have to be laid out.

The next step is to modify the basic route (routes) to include the additional pickup locations that will have to be serviced to complete the load. These modifications should be made so that the same general area is serviced with each collection route. For large areas that have been subdivided and that are serviced daily, it will be necessary to establish basic routes in each subdivided area; in some cases, between them, depending upon the number of trips to be made per day.

Step 4. When the collection routes have been laid out, the quantity of waste to be collected and the haul distance for each route should be determined. In some cases it may be necessary to readjust the collection routes to balance the work load. After the routes have been established, they should be drawn on the master map.

Example 8-6 Layout of collection routes for an industrial park. Lay out collection routes for both a hauled container and a stationary container collection system for the industrial service area shown in the accompanying map. There are, as shown on the map, a total of 28 pickup locations and 32 containers. The total quantity of waste to be collected each week is 277 yd^3. The map and the information it contains would be prepared as the first step in the layout of collection routes. Assume the following conditions apply:

1. Containers with a collection frequency of twice per week must be picked up on Tuesday and Friday.
2. Containers with a collection frequency of three times per week must be picked up on Monday, Wednesday, and Friday.
3. Containers may be picked up from any side of the intersection where they are stationed.
4. Start and finish each day at the dispatch station.
5. For the hauled container system, collection will be provided Monday through Friday.



6. Hauled containers are exchanged rather than being returned to the location from which they were picked up (see Fig. 8-14*b*).
7. For the stationary container system, collection will be provided only 4 days/wk (Monday, Tuesday, Wednesday, and Friday) with only 1 trip/day.
8. For the stationary container system, the collection vehicle will be a self-loading compactor with a capacity of 35 yd^3 and a compaction ratio of 2.

Solution

1. Hauled container system
   (*a*) Set up a summary table for the collection operation using the data reported in the service area map (Step 2 in the layout of collection routes). The summary table and a brief description of the entries in the table are presented below.
      i. The number of pickup locations and containers requiring three collections per week are entered in Row 1. As noted in the problem statement, these containers must be emptied on Monday, Wednesday, and Friday.
      ii. The number of pickup locations requiring two collections per week are entered in Row 2. These containers must be emptied on Tuesday and Friday.
      iii. The additional number of containers receiving once per week service that must be emptied each collection day are entered in Row 3. The containers to be emptied are distributed so that an equal number of containers are emptied each work day.

Collection frequency, times/wk	Number of pickup locations	Total no. of containers	Number of trips/wk[a]	Number of containers (receiving the same collection frequency) emptied per day				
				Mon.	Tues.	Wed.	Thurs.	Fri.
3	2	2	6	2	—	2	—	2
2	4	4	8	—	4	—	—	4
1	22	26	26	6	4	6	8	2
Total	28	32	40	8	8	8	8	8

[a] In the hauled container system each container to be emptied corresponds to a trip.

   (*b*) Lay out balanced collection routes for each day of the week by successive trials (Steps 3 and 4 in the layout of collection routes). The routes will vary from one solution to another, but containers 11 and 20 must be picked up on Monday, Wednesday, and Friday, and containers 17, 27, 28, and 29 must be picked up on Tuesday and Friday. The optimum solution will be to have an equal number of containers picked up on each day as well as equal distances driven on each day.

   The resulting weekly routes and travel distances are shown in the tabulation on page 233. With the exception of the first container emptied on each route, the distance reported for each container includes the distance from Point B to the container location and the distance from the container location to Point B. The distance reported for the first container includes the distance from the dispatch station and the distance from the container location to Point B.

2. Stationary container system
   (*a*) Set up a summary table for the collection operation using the data reported in the service area map (Step 2 in the layout of collection routes), as follows:

Order of container pickup	Mon.		Tues.		Wed.		Thurs.		Fri.	
	Cont. no.	Dist.[a]	Cont. no.	Dist.[a]	Cont. no.	Dist.[a]	Cont. no.	Dist.[a]	Cont. no.	Dist.[a]
	A→1	6.2	A→7	1.1	A→3	5.9	A→2	5.9	A→13	1.6
1	1→B	11.2	7→B	4.5	3→B	8.8	2→B	8.8	13→B	4.9
2	B→8→B	20.7	B→10→B	17.6	B→9→B	15.3	B→6→B	12.7	B→5→B	16.3
3	B→11→B	14.1	B→14→B	14.0	B→4→B	17.6	B→18→B	6.0	B→11→B	14.1
4	B→20→B	10.0	B→17→B	9.3	B→11→B	14.1	B→15→B	9.6	B→17→B	9.3
5	B→22→B	4.4	B→26→B	12.1	B→12→B	8.8	B→16→B	9.6	B→20→B	10.0
6	B→30→B	5.6	B→27→B	10.9	B→20→B	10.0	B→24→B	16.0	B→27→B	10.9
7	B→19→B	6.9	B→28→B	8.0	B→21→B	4.4	B→25→B	14.0	B→28→B	8.0
8	B→23→B	4.7	B→29→B	8.0	B→31→B	1.1	B→32→B	1.7	B→29→B	8.0
	B→A	5.0	B→A	5.0	B→A	5.0	B→A	5.0	B→A	5.0
Total distance[b]		88.8		90.5		91.0		89.3		88.1

[a] Distance, in thousand feet.

[b] Total distance driven between Points A and B, in thousand feet, during each collection day.

i. The quantity of waste to be collected from the locations requiring three collections per week is entered in Row 1. As noted in the problem statement, the waste from these locations must be collected on Monday, Wednesday, and Friday.
ii. The quantity of waste to be collected from the locations requiring two collections per week is entered in Row 2. These containers must be emptied on Tuesday and Friday.
iii. The additional quantity of waste that can be collected on each collection route is determined and entered in Row 3. Note that the maximum quantity of wastes that can be collected per day is 70 yd^3 [35 yd^3 × 2 (compaction ratio)].

Collection frequency, times/wk	Number of pickup locations	Total waste, yd^3/wk	Quality of wastes collected per day, yd^3			
			Mon.	Tues.	Wed.	Fri.
3	2	51	17	—	17	17
2	4	48	—	24	—	24
1	22	178	53	44	52	29
Total	28	277	70	68	69	70

(*b*) Lay out balanced collection routes by successive trials in terms of quantity of wastes collected (Steps 3 and 4 in the layout of collection routes). Collection routes for the stationary container system will vary, but containers 11 and 20 must be picked up on Monday, Wednesday, and Friday, and containers 17, 27, 28, and 29 must be picked up on Tuesday and Friday. Again, the optimum solution will be to have an equal amount of waste collected on each collection route as well as equal distances driven on each route.

The resulting routes and travel distance are shown in the following tabulation. The travel distance between Points A (dispatch station) and B includes the distance

Order of pickup	Mon.		Tues.		Wed.		Fri.	
	Cont. no.	yd^3	Cont. no.	yd^3	Cont. no.	yd^3	Cont. no.	yd^3
1	5	8	2	6	7	7	13	5
2	4	8	3	6	6	10	11	9
3	1	8	10	8	11	9	17	7
4	8	9	24	9	15	6	18	8
5	9	9	25	4	16	6	19	4
6	11	9	26	8	20	8	23	6
7	14	10	28	5	30	5	20	8
8	20	8	29	5	31	7	27	7
9	—	—	27	7	222	7	28	5
10	—	—	17	7	31	5	29	5
11	—	—	12	4	—	—	32	5
Total		69		69		69		70
Dist.[a]	19,000		22,000		17,000		21,000	

[a] Total distance driven between Points A and B in feet on each collection route.

from Point A to the first container pickup location, the distance traveled on the collection route, and the distance from the last container pickup location to Point B.

Comment. The economic advantage of the stationary container system is apparent in this example. However, if container sizes greater than about 12 yd^3 are needed, the stationary container system can no longer be used.

Collection Route Layout—Steps 2, 3, and 4 for Stationary Container System (with Manually Loaded Collection Vehicles). Steps 2, 3, and 4 for a stationary container system that is manually loaded can be outlined as follows.

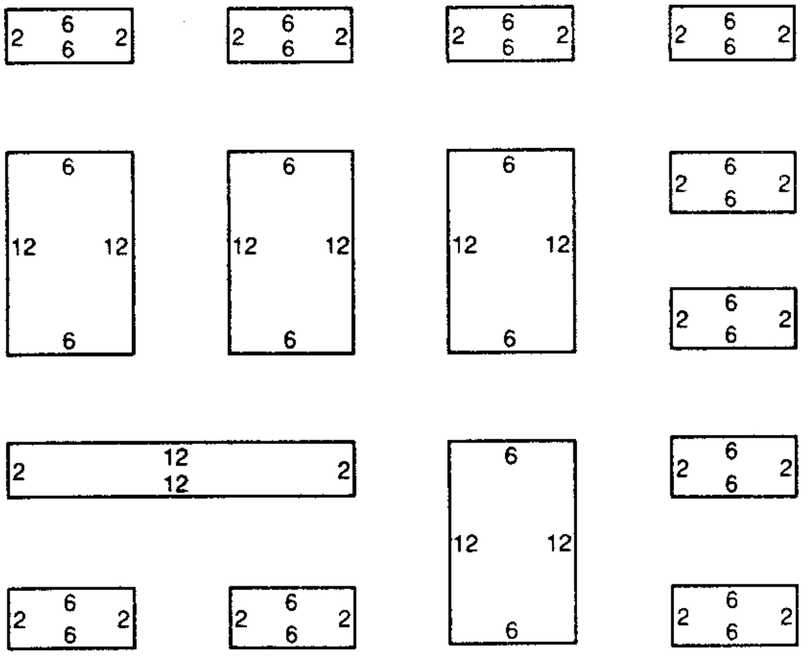
Step 2. Estimate the total quantity of wastes to be collected from pickup locations serviced each day that the collection operation is conducted. Using the effective volume of the collection vehicle (nominal collection vehicle volume × compaction ratio), determine the average number of residences from which wastes are to be collected during each collection trip.

Step 3. Once the foregoing data are known, the layout of collection routes can proceed as follows. Starting from the dispatch station (or garage) lay out collection routes that include all of the pickup locations to be serviced during each collection route. These routes should be laid out so that the last of these locations is nearest the disposal site.

Step 4. When the collection routes have been laid out, the actual container density and haul distance for each route should be determined. Using these data, the labor requirements per day should be checked against the available work time per day. In some cases it may be necessary to readjust the collection routes to balance the work load. After the routes have been established, they should be drawn on the master map.

Example 8-7 Layout of residential collection routes. Lay out collection routes for the residential area shown in the accompanying figure on page 236. The service area map would be prepared as the first step in the layout of collection routes. Assume that the following conditions apply:

1. General
   (*a*) Occupants per residence = 3.5
   (*b*) Solid waste collection rate = 3.5 lb/person · d
   (*c*) Collection frequency = once/wk
   (*d*) Type of collection service = curb
   (*e*) Collection crew size = one person
   (*f*) Collection vehicle capacity = 14 yd^3
   (*g*) Compacted specific weight of solid waste in collection vehicle = 540 lb/yd^3



2. Collection route constraints
   (*a*) No U-turns in streets
   (*b*) Collection from each side of the street with stand-up right-hand-drive collection

Solution

1. Develop data needed to establish collection routes (Step 2 in the layout of collection routes).
   (*a*) Determine total number of residences from which wastes are to be collected.

$$\text{Residences} = 10(16) + 4(36) + 1(28) = 332$$

   (*b*) Determine the compacted volume of solid waste to be collected per week.

$$\begin{aligned}\text{Vol/wk} &= [(332 \text{ residences} \times 3.5 \text{ persons/residence} \\ &\quad \times 3.5 \text{ lb/person} \cdot \text{d} \times 7 \text{ d/wk})]/(540 \text{ lb/yd}^3) \\ &= 52.7 \text{ yd}^3\end{aligned}$$

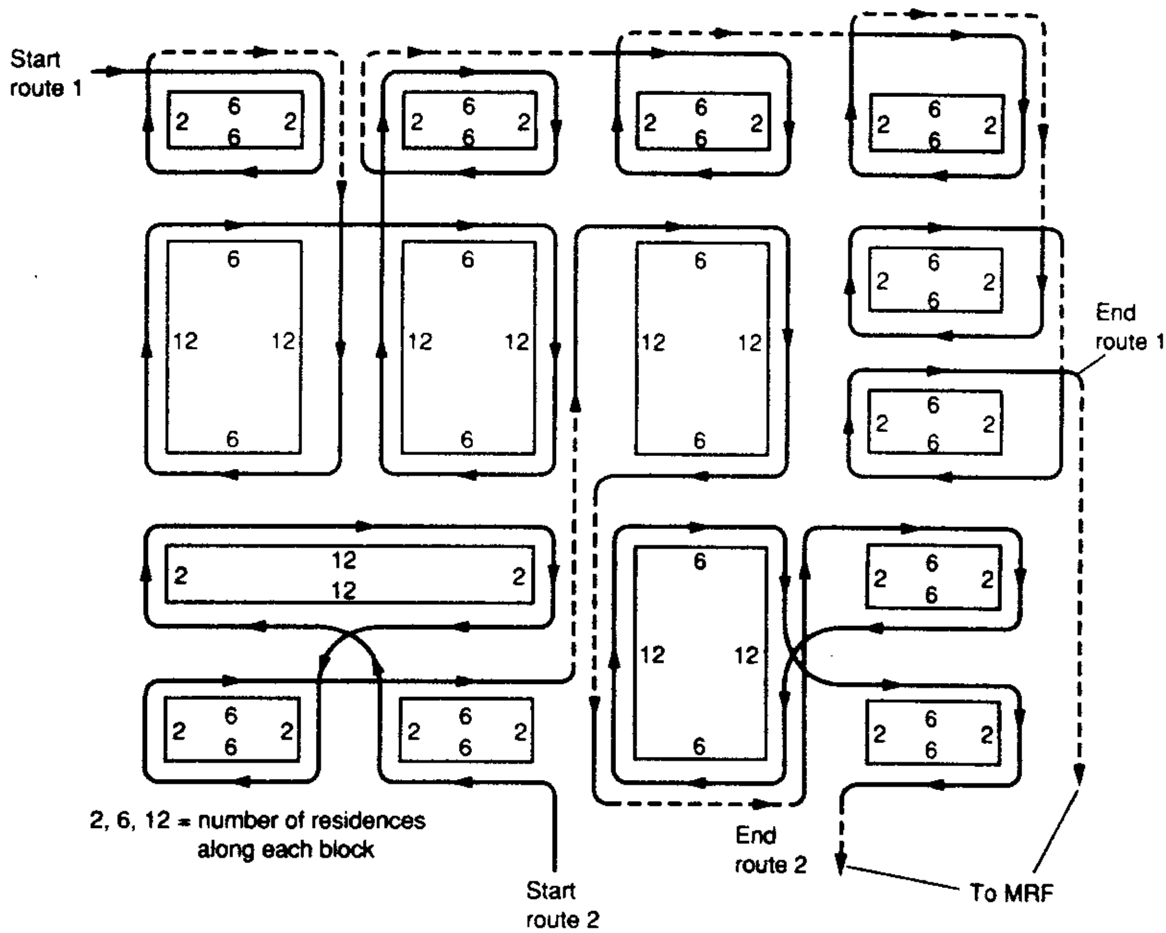
   (*c*) Determine the number of trips required per week.

$$\text{Trip/wk} = \frac{52.7 \text{ yd}^3\text{/wk}}{14 \text{ yd}^3\text{/trip}} = 3.76; \text{ Use 4}$$

   (*d*) Determine the average number of residences from which wastes are to be collected on each collection trip.

$$\text{Residences/trip} = 332/4 = 83$$

2. Lay out collection routes by successive trials using the route constraints cited above as a guide (Step 3 in the layout of collection routes). Four typical routes are shown in the following figure.



Comment. The effectiveness of the collection routes can be assessed by the amount of route overlap shown by the dotted lines. An interesting problem for the reader is to determine if four collection routes can be laid out without any overlap.

Schedules

A master schedule for each collection route should be prepared for use by the engineering department and the transportation dispatcher. A schedule for each route, which includes the location and order of each pickup point to be serviced, should be prepared for the driver. In addition, a route book should be maintained by each truck driver. The driver uses the route book to check the location and status of accounts. It is also a convenient place in which to record any problems with the accounts. The information contained in the route book is useful in modifying the collection routes.

8-5 ALTERNATIVE TECHNIQUES FOR ANALYSIS OF COLLECTION SYSTEMS

Interest in the analysis of solid waste collection systems arises from the desire to improve (optimize) the operation of existing systems and to develop data and techniques that can be used to design or evaluate new or future systems. In the past and at present the design and operation of most solid waste collection systems are based largely on experience and intuition. In an effort to operate existing systems and design new ones more efficiently, techniques and tools—such as systems analysis, operations research, system simulation, and systems and operations modeling—developed in related areas have from time to time been applied to the analysis of waste collection [2, 3, 6]. One of the major reasons that these techniques have not been used more widely is the enormous cost associated with the collection and processing of field data. A new approach to routing combines a data base of collection information with a geographic information system containing street mapping data.

8-6 DISCUSSION TOPICS AND PROBLEMS

8-1. Drive, walk, or pedal around your community and identify the principal types of systems and equipment used for the collection of residential and commercial solid wastes. Select two of the more common systems and time the various activities associated with the collection of wastes. How do your values compare with those given in this chapter? If your values are significantly different, explain why.

8-2. Drive, walk, or pedal around your community and identify the principal types of service and equipment used for the collection of source-separated wastes from residential and commercial sources.

8-3. How are yard wastes (e.g., grass clippings, brush, and tree trimmings) collected in your community? If your community does not collect yard wastes separately, is the separate collection of yard wastes feasible given the waste management system that is now used? What modifications would be required if separate collection of yard wastes were to be instituted? If your community collects yard wastes separately, describe the operation in terms of its basic operations (e.g., pickup, haul, at-site time, etc.).

8-4. Determine the haul equation constants *a* and *b* for the following data (A, B, or C to be selected by your instructor.)

Average haul speed (*y*), mi/h	Round-trip distance(*x*), mi/trip		
	A	B	C
10.0	0.9	1.0	1.1
20.0	2.9	3.1	4.6
25.0	4.0	4.8	8.0
29.0	5.5	6.5	16.0
30.0	6.0	7.0	21.0
35.0	8.0	10.5	
39.0	10.0	16.0	
40.0	11.0	20.0	
45.0	15.5		
50.0	28.0		

8-5. You are the city engineer in a small rural town. During a council meeting you are asked to compare the satellite method of collection with the more traditional curb-and-alley collection service that the city is currently providing. Startled, because you had fallen asleep during the preceding 4-h debate concerning the merits of the city slogan, you try to collect your thoughts. What are some of the important considerations that must be brought out in your discussion?

8-6. Develop an equation similar to those presented in this chapter that can be used to determine the labor requirements for a stationary container system employing satellite collection vehicles (see Fig. 8-2).

8-7. Develop an expression similar to Eq. (8-13) that can be used to estimate the time required for the curbside collection of source-separated wastes. Assume the following conditions apply:

(*a*) Three separate containers will be used for (i) mixed paper, (ii) commingled plastics and glass, and (iii) commingled aluminum and tin cans.

(*b*) Some homeowners will also periodically put out cardboard for separate collection.

8-8. Because of a difference of opinion among city staff members, you have been retained as an outside consultant to evaluate the collection operation of the city of Davisville. The basic question centers around the amount of time spent on off-route activities by the collectors. The collectors say that they spend less than 15 percent of each 8-h workday on off-route activities; management claims that the amount of time spent is more than 15 percent. You are given the following information that has been verified by both the collectors and management:

(*a*) A hauled container system, without container exchange, is used.

(*b*) The average time spent driving from yard to the first container is 20 min, and no off-route activities occur.

(*c*) The average pickup time per container is 6 min.

(*d*) The average time to drive between containers is 6 min.

(*e*) The average time required to empty the container at the disposal site is 6 min.

(*f*) The average round-trip distance to the disposal site is 10 mi/trip, and the haul equation $(a + bx)$ constants are $a = 0.004$ h/trip and $b = 0.02$ h/mi.

(*g*) The time required to redeposit a container after it has been emptied is 6 min.

(*h*) The average time spent driving from the last container to the corporation yard is 15 min, and no off-route activities occur.

(*i*) The number of containers emptied per day is 10.

From this information, determine whether the truth is on the side of the collectors or the management.

8-9. The amount of solid wastes generated per week in a large residential complex is about 600 yd^3. There are two containers, each with a capacity of 40 gal, at the rear of every house. The solid wastes are collected by a two-person crew using a 35-yd^3 manually loaded compactor truck once a week. Determine the time per trip and the weekly labor requirements in person-days. The disposal site is located 15 mi away; haul-time constants a and b are 0.022 h/trip and 0.022 h/mi, respectively; the container utilization factor is 0.7; and the compaction ratio is 2. Assume that collection is based on an 8-h day.

8-10. A city desires to determine the impact of a new subdivision on solid waste collection services. The subdivision will add 150 new houses. A two-person crew will collect the wastes twice a week, using 24-m^3 manually based loaded compactor trucks. The allowable container size is 0.14 m^3. It is estimated that there will be 3.2 persons per household and that each person will dispose of 2.5 kg of waste daily. Determine the number of containers that will be needed per household, the average container utilization factor, and the weekly labor requirement in person-days. The compaction ratio for the collection vehicle is 2.5, the average density of the solid wastes in the containers is 120 kg/m^3, the disposal site is located 25 km away, and the haul-time constants a and b are 0.08 h/trip and 0.015 h/km, respectively. Collection is during an 8-h day. Collection is at curbside except for elderly persons (about 5 percent) who receive backyard service.

8-11. A new residential area composed of 800 low-rise detached dwellings is about to be occupied. Assuming that either two or three trips per day will be made to the disposal site, design the collection system and compare the two alternatives. The following data are applicable:

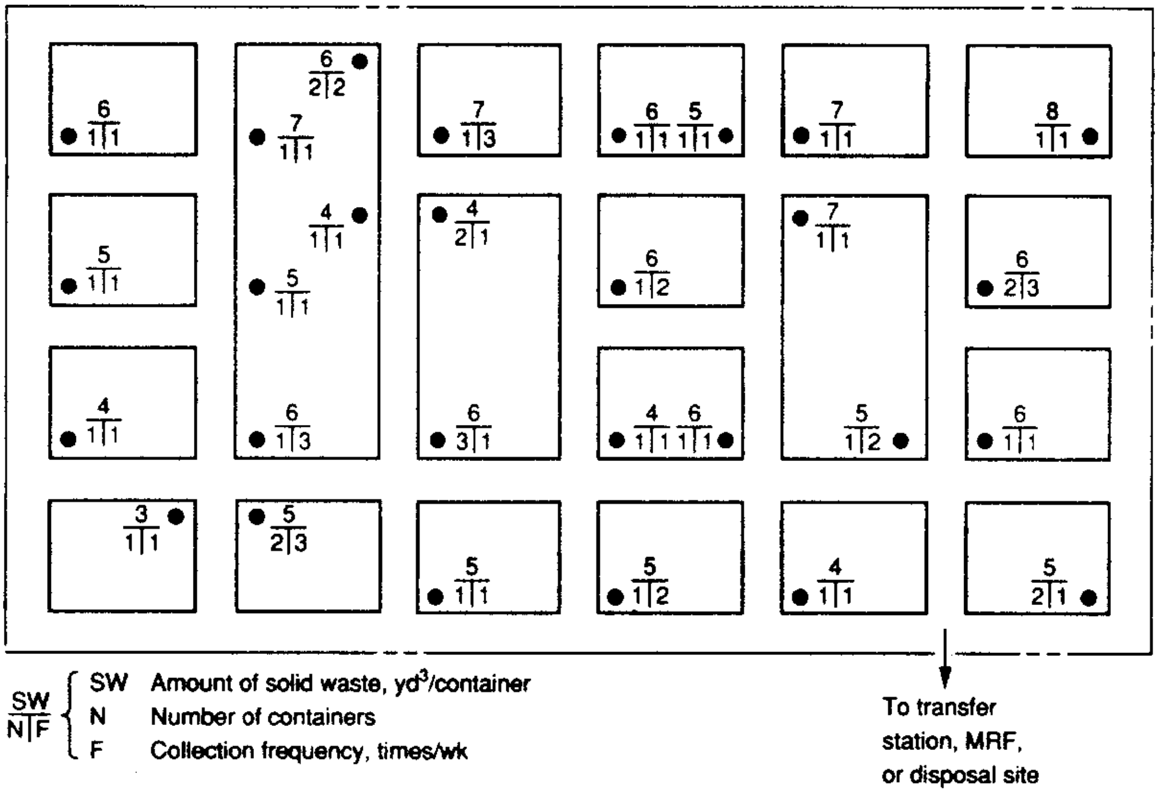
(*a*) Solid waste generation rate = 0.032 yd^3/home · d
(*b*) Containers per service = 2
(*c*) Type of service = 75 percent curbside and 25 percent rear of house
(*d*) Collection frequency = once per week
(*e*) Collection vehicle is a rear-loaded compactor with a compaction ratio of 2.5.
(*f*) Length of workday = 8 h
(*g*) Collection crew = 2 persons
(*h*) Round-trip haul distance = 20 mi
(*i*) Haul constants: a = 0.08 h/trip and b = 0.025 h/mi
(*j*) At-site time per trip = 0.083 h/trip

8-12. TT&E Corporation has four business locations that are each conveniently located 5 mi apart and 5 mi from the disposal site. TT&E presently uses a conventional hauled container system with large open-top containers. It has been suggested to TT&E that money could be saved by renting a fifth container from the waste collection company at a cost of $120/month and switching the operation to the container-exchange mode (see Fig. 8-14*b*). Each location will be serviced 8 times per month. The extra container will be stored at the collection company's dispatch station. Assuming that the operating costs are $20/h, compute the costs for both systems. Is it a wise decision for TT&E to rent the fifth container? Assume that a = 0.034 h/trip and b = 0.029 h/mi for all cases. State clearly any additional assumptions.

8-13. You and your friend are looking for some part-time work. You live in a small rural community that does not receive regular waste collection service. Your friend thinks it would be a good idea to provide waste collection service using your new $\frac{3}{4}$-ton four-wheel-drive pickup truck. There are 30 houses, and each one uses two 32-gal containers. All the houses would receive backyard carry service once per week. The haul constants are 0.08 h/trip and 0.025 h/mi. Assume that the at-site time equals 0.5 h. The round-trip haul distance to the disposal site is 32 mi. The size of the pickup truck bed is 6 × 8 × 3 ft. Assuming that, working together, you and your friend can devote 10 h/wk to this project, is it operationally feasible?

8-14. You have been called to submit a proposal to evaluate your university's solid waste collection operation. Prepare a proposal, in outline form, to be submitted to the university. Note clearly the major divisions or tasks into which the work effort would be divided. Based on your knowledge to date, estimate the person-months of effort that would be required to do the work outlined in your proposal. Use an outline format in answering this question.

8-15. Lay out collection routes for both a hauled container and stationary container collection system for the industrial service area shown in the accompanying map. There are a total of 28 pickup locations and 35 containers. The total quantity of waste to be collected each week is 289 yd^3. Using an arbitrary scale, determine the distance



traveled during the collection operation for each route for each collection system. The map and the information it contains would be prepared as the first step in the layout of collection routes. Assume the following conditions apply:

(*a*) Containers with a collection frequency of twice per week must be picked up on Tuesday and Friday.

(*b*) Containers with a collection frequency of three times per week must be picked up on Monday, Wednesday, and Friday.

(*c*) Containers may be picked up from any side of the intersection where they are located.

(*d*) The hauled container system is of the type where the empty containers are returned to the same location where they were picked up full (see Fig. 8-14*a*).

(*e*) For both collection systems, collection will be provided Monday through Friday, as required.

(*f*) For the stationary container system, the collection vehicle will be a self-loading compactor with a capacity of 35 yd^3 and a compaction ratio of 2.8.

8-16. Lay out collection routes for the residential area shown in the figure on page 242. Assume that the following data are applicable:

(*a*) Occupants per residence = 3.1

(*b*) Solid waste generation rate = 3.75 lb/capita · d

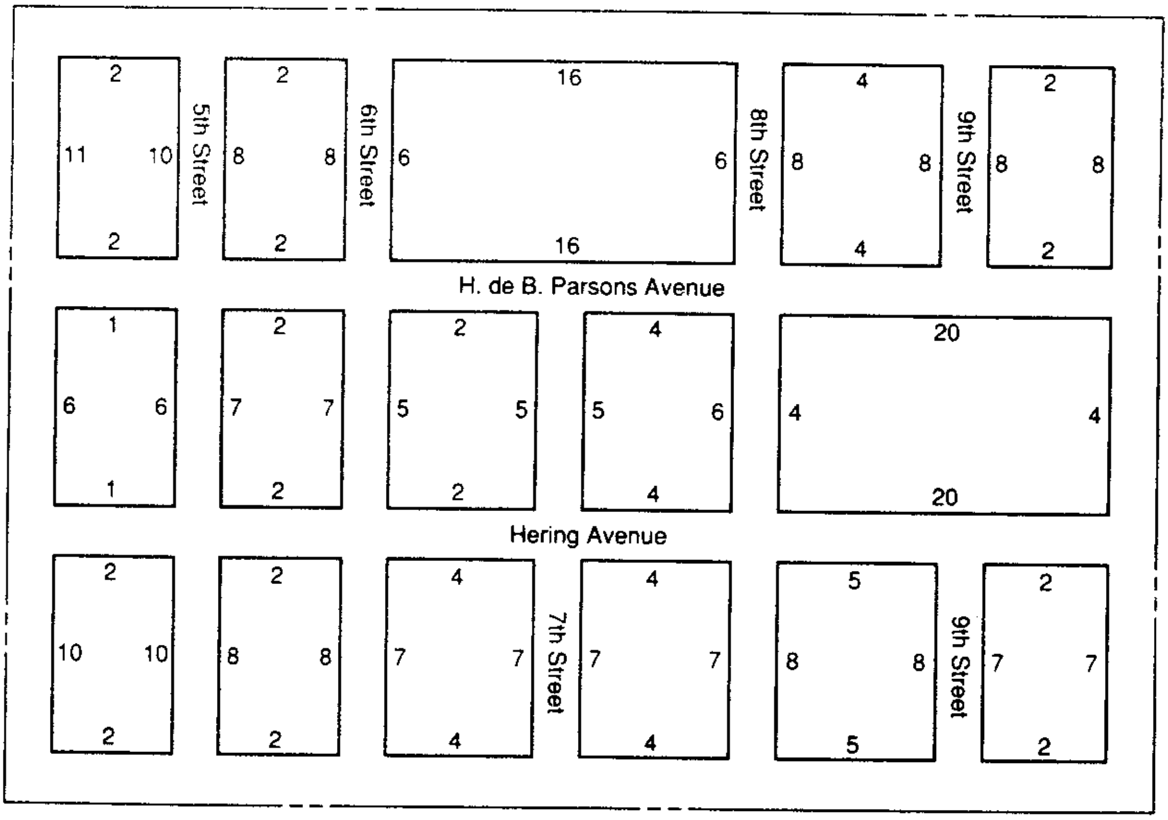
(*c*) Collection frequency = once per week

(*d*) Type of collection service = curb

(*e*) Collection crew size = 1 person

(*f*) Collection vehicle capacity = 26 yd^3

(*g*) Compacted specific weight of solid wastes in collection vehicle is equal to 590 lb/yd^3.



3, 6, 10, 15 = number of residences along each block

8-17. Lay out collection routes for the area shown in the figure given in Problem 8-16 using data given in Problem 8-16, assuming that 5th and 8th streets are one-way running from the south to north and that 6th street is one-way running from north to south. All of the other streets and avenues are two-way.

8-18. Lay out collection routes for the area shown in the figure given in Problem 8-16 using the data given in Problem 8-16, assuming that H. de. B Parsons Street is one-way running form the west to east and that Hering Street is one-way running from east to west. All of the other streets are two-way.

8-19. Lay out collection routes for the residential area shown in the figure on page 243. Assume that the following data are applicable:

(*a*) Occupants per residence = 2.8

(*b*) Solid waste generation rate = 3.5 lb/capita · d

(*c*) Collection frequency = once per week

(*d*) Type of collection service = curb

(*e*) Collection crew size = 1 person

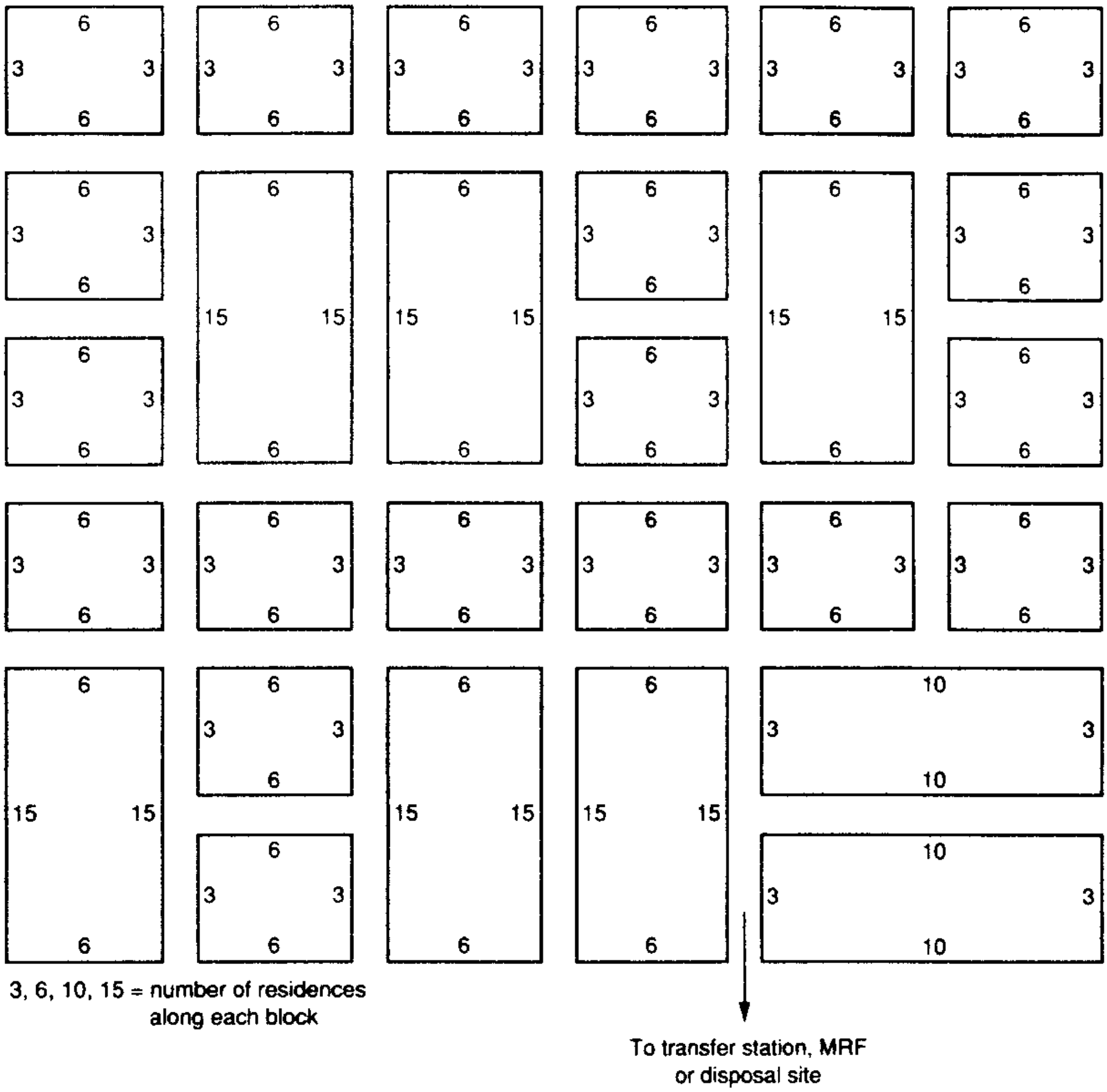
(*f*) Collection vehicle capacity = 24 yd^3

(*g*) Compacted specific weight of solid wastes in collection vehicle is equal to 650 lb/yd^3.

(*h*) Collection is from each side of the street using a standup right-hand-drive collection vehicle.

(*i*) No U-turns in streets

8-20. Solve Problem 8-19 using a collection vehicle with a capacity of 20 yd^3, assuming the compacted specific weight is equal to 575 lb/yd^3.



8-21. Lay out collection routes for the residential area shown in the figure on page 244. Assume that the following data are applicable:

(*a*) Occupants per residence = 3.1

(*b*) Solid waste generation rate = 3.8 lb/capita · d

(*c*) Collection frequency = once per week

(*d*) Type of collection service = curb

(*e*) Collection crew size = 1 person

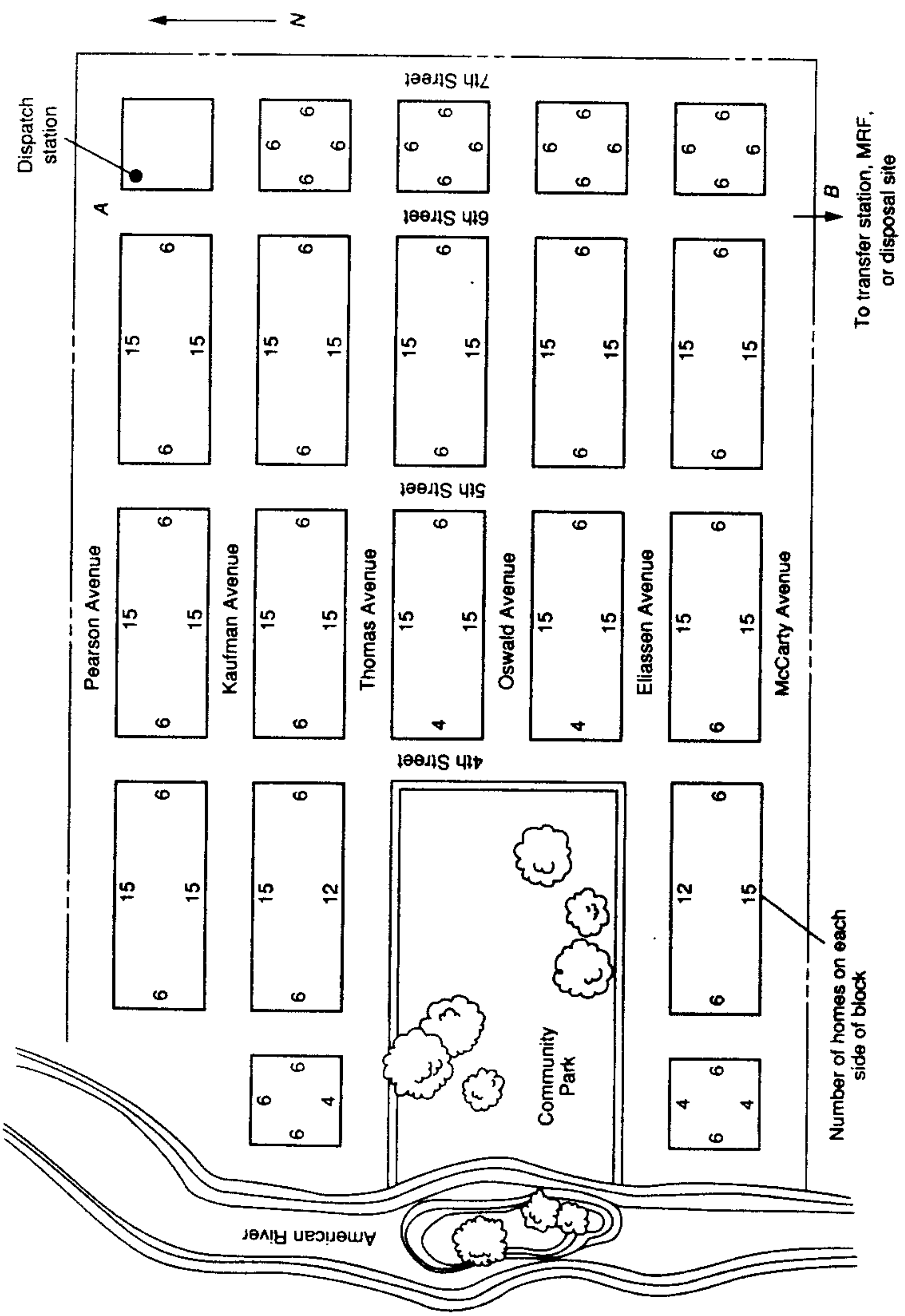
(*f*) Collection vehicle capacity = 30 yd^3

(*g*) Compacted specific weight of solid wastes in collection vehicle is equal to 625 lb/yd^3.

(*h*) Collection is from each side of the street using a standup right-hand-drive collection vehicle.

(*i*) No U-turns in streets

8-22. Solve Problem 8-21 using a collection vehicle with a capacity of 24 yd^3 assuming the compacted specific weight is equal to 585 lb/yd^3.


N
Dispatch station
A
B
To transfer station, MRF, or disposal site
7th Street
6th Street
5th Street
4th Street
Pearson Avenue
Kaufman Avenue
Thomas Avenue
Oswald Avenue
Eliassen Avenue
McCarty Avenue
Community Park
American River
Number of homes on each side of block

8-23. The household waste generation rates given below were observed over a period of time on a typical collection route. Assuming that curbside density of the waste is 120 kg/m^3, estimate the percentage of the time a 24-m^3 collection truck with a compaction ratio of 2.5 will need more than one trip to service 82 households. The observed waste generation rates are 42, 60, 35, 27, 50, 94, 72 kg/household · wk.

8-24. In the late 1960s and early 1970s much was written about the use of simulation and other techniques from the field of operations research for the routing of collection vehicles (e.g., Refs. 3, 4, and 7). Based on a review of one or two articles from that period (i.e., 1965 to 1975), prepare an analysis of why the techniques proposed have not been adopted to any major extent. Was the research of the period ahead of its time?

8-25. During the late 1980s the processing speed and capacity of relatively inexpensive desktop computers made the use of geographic information systems feasible for the routing of collection vehicles. Prepare a review of such systems using recent issues of trade publications such as *Waste Age* and *Public Works*. Why is this approach more feasible than the mainframe computer-based techniques discussed in Problem 8-24?

8-7 REFERENCES

1. Bergen County Utilities Authority: *Bergen County Apartment Recycling Manual*, Little Ferry, NJ, 1988.
2. Liebman, J. C.: *Routing of Solid Waste Collection Vehicles*, Final Report on Project 801289, Office of Research and Monitoring, U.S. Environmental Protection Agency, Washington, DC, 1973.
3. Quon, J. E., A. Charnes, and S. J. Wenson: Simulation and Analysis of a Refuse Collection System, *Proceedings ASCE, Journal of the Sanitary Engineering Division*, Vol. 91, No. SA5, 1965.
4. Shuster, K. A. and D. A. Schur: *Heuristic Routing for Solid Waste Collection Vehicles*, Publication SW-113, U.S. Environmental Protection Agency, Washington, DC, 1974.
5. Tchobanoglous, G. and G. Klein: *An Engineering Evaluation of Refuse Collection Systems Applicable to the Shore Establishment of the U.S. Navy*, Sanitary Engineering Research Laboratory, University of California, Berkeley, 1962.
6. Truitt, M. M., J. C. Liebman, and C. W. Kruse: *Mathematical Modeling of Solid Waste Collection Policies*, Vols. 1 and 2, Public Health Service Publication 2030, U.S. Department of Health, Education, and Welfare, Washington, DC, 1970.
7. University of California: *An Analysis of Refuse Collection and Sanitary Landfill Disposal*, Technical Bulletin 8, Series 37, University of California Press, Berkeley, 1952.